Weeds

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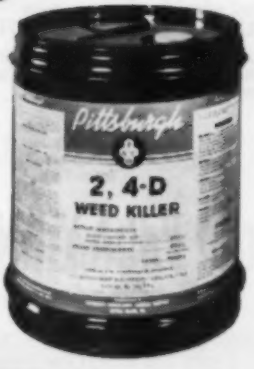

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First National Weed Control Conference

Over 700 weed workers from state, federal and industrial institutions interested in the research, development, extension, teaching and regulatory phases of weed control attended the First National Weed Control Conference, December 8 & 9, 1953 at Kansas City, Missouri.

The North Central Weed Control Conference was host for the National Conference and also held its 10th annual meeting following the National meeting.

Approximately 60 scientific papers covering all phases of the weed control program were presented at the National Conference. Abstracts of these papers are scheduled for publication in the Proceedings of the Conference. Authors have been requested to submit their papers to WEEDS for publication.

The First National Weed Conference and the initiation and growth of WEEDS are examples of the significance and importance of the rapidly growing science of weed control. The impetus of these two accomplishments should serve to strengthen the status of weed control. Certainly an important step has been taken in forming a national weed organization which will meet the needs of all those interested in the various aspects of weed control.

We take this opportunity to express thanks to the officers and committeemen of the Association of Regional Weed Control Conferences and of the North Central Weed Control Conference for giving generously of their time and efforts in making the First National Weed Control Conference so highly successful.

New Editor for *Weeds*

At a meeting of the Editorial Board on December 7, during the meeting of the First National Weed Control Conference at Kansas City, Missouri, Dr. C. E. Minarik, Camp Detrick, Frederick, Maryland, was appointed new editor of the WEEDS journal. Authors desiring to publish in the WEEDS journal should submit two copies of their manuscripts to the editor.

The officers of the Association of Regional Weed Control Conferences and the Editorial Board are pleased to announce Dr. Minarik's appointment as the new editor of WEEDS. We are sure that authors, readers and advertisers will be looking forward to working with the new editor to assure WEEDS of a bright future.

It is with pleasure and confidence that we transfer the editorship and editorial offices of WEEDS from this Division to Dr. C. E. Minarik, Camp Detrick, Frederick, Maryland.

I am sure that the subscribers to WEEDS join the Editorial Board at this time in expressing thanks to Dr. R. D. Sweet who has given generously of his time and efforts as the first editor of WEEDS.

W. C. Shaw
Division of Weed Investigations
Agricultural Research Service
U. S. Dept. of Agriculture

Weeds

JOURNAL OF THE ASSOCIATION OF REGIONAL WEED CONTROL CONFERENCES.

VOLUME II OCTOBER 1953 NUMBER 4

Gross Morphological Responses of the Rice Plant to 2,4–D[1]

PETER B. KAUFMAN[2]

Department of Botany, University of California, Davis, California

IN THE years that 2,4–D has been used as a selective herbicide in agricultural areas, an increasing number of reports of its injury to crops has been published. As a result of extensive investigations, lists of susceptible and resistant crops have appeared. Some of the extremely susceptible crops include cotton, sugar beets, alfalfa, tomatoes, peas, beans, cabbage, broccoli, lettuce, grapes, and many others. In response to numerous reports of 2,4–D injury to various small grains, we now consider these plants as being relatively susceptible to 2,4–D at certain stages of development also. The morphological injuries reported may be just as severe as in the case of some of the above-mentioned plants.

Since 2,4–D was first used for the control of aquatic weeds in rice fields in 1946, numerous reports from the rice-growing areas in California and the southeast indicate that 2,4–D has caused varying degrees of injury to the rice plant. Most accounts of the injury have pertained to morphological aberrations of the emerging and mature panicles, in which case the "heads" appear greatly distorted at maturity. This resulted in significant reductions in the number of grains per panicle, and hence important effects on yields.[3] Rice growers, farm advisors, and research workers in weed control could not explain (1) why the injury was so variable in certain rice-growing regions during a given season, (2) why injury was not serious during some seasons and was an important factor in reduction of yields in other seasons, (3) the conditions under which the injury occurred,

[1]A portion of a research investigation conducted to fulfill partially the requirements for Ph.D. degree in botany. The writer wishes to thank Dr. A. S. Crafts and Dr. Vernon I. Cheadle of the Department of Botany, Mr. William A. Harvey and Mr. Loren Davis of the Agricultural Extension Service, Mr. A. H. Williams, formerly in charge of the Rice Experiment Station at Biggs, California, and the California Rice Growers Association for their assistance and suggestions during the course of this part of the investigation.

[2]Teaching Assistant in weed control, Department of Botany, University of California, Davis, California.

[3]Up to twenty-five percent reduction according to yield data obtained from randomized replicated plots by Mr. A. H. Williams, formerly in charge of the Rice Experiment Station at Biggs, California. The writer has recorded numbers of grains per panicle in severely injured and control heads; in one case, the average of eleven different recordings showed 32 as compared with 109 grains from injured and control panicles, respectively.

and (4) how injury might be prevented. Thus, an extensive investigation was initiated in California in 1950 to attempt to answer these questions.

The several facets of this investigation include a developmental gross morphological and anatomical study of healthy and 2,4–D injured shoots, an inquiry into some of the factors influencing the occurrence and magnitude of 2,4–D injury, and a study of practices which might prevent the injury. It is primarily with regard to the first two mentioned phases that the present paper is concerned.

LITERATURE REVIEW

The reports on the gross morphological responses of grasses to 2,4–D are numerous. A survey of literature emanating from Europe and the U.S.A. during the past eight years indicates that earlier descriptions of these responses usually have been incorporated into more general studies, whereas more recently entire papers have been devoted to the various types of injury.

Since the available information on the effect of 2,4–D on cereals is too extensive to consider here, only some of the salient features will be mentioned. The following list of gross morphological aberrations reveals the wide range of variability in the types of responses: (a) *root responses* – fasciated adventitious roots (20), discoloration of roots (29, 39), hypertrophy or fasciation of root hairs and death of roots (29), proliferation of brace roots (6, 19), increase in the number of root initials in swollen shoot bases and along primary roots (6), emergence of large stubby roots (39, 48), and accelerated growth of the root system (48); (b) *stem responses* – twisting or breaking of the rachis of the inflorescence due to partial or obstructed emergence of the "head" from the sheath (5, 6, 41, 44, 54), lodging and bending of stems (6, 19, 24, 32, 41, 50), occurrence of brittle stems (6, 45), excessive elongation of inflorescence internodes (41), swelling of base of the stem (6, 8, 32, 48), reduction of tillering (6, 8, 48), and death of stems (32); (c) *leaf responses* – incomplete differentiation of lamina and sheath (8), irregular unfolding of leaves (8), increase in intensity of green coloration (27, 32), yellowing (29, 36), scorch (54, 55), wilting (29), stiffening (27, 39), "rolling" (19, 20, 27, 46), occurrence of "onion" or tubular leaves (5, 6, 14, 32, 39, 41, 49), decrease in size (32, 38), and death of leaves (32); (d) *inflorescence responses* – malformed ears (1, 2, 8, 9 ,55), "dropping" of heads (41), delayed heading (6), twinning of inflorescences (5, 27, 32), "clubbed" and "ragged" heads (41), inhibition of spikelet development (5, 32), presence of opposite spikelets (6, 41), presence of supernumerary spikelets and florets (5, 27, 41), sterility of florets (6, 27, 32, 48), tendency for sterile florets to become fertile (54), absence of glumes, (6), presence of sterile glumes (6), twisting, fusion, excessive enlargement, and failure of splitting of glumes (5, 6, 27, 32), fusion of lemmas (6, 27), presence of supernumerary grains (5), discoloration of grains (48), and reduction in number and weight of grains (6, 27, 48). Although the above citations are by no means complete, it becomes

clearly apparent that 2,4–D, in altering the metabolism of grasses, may induce a striking array of morphological aberrations of both root and shoot systems. This is certainly strong evidence for refutation of the commonly held idea that grasses are resistant to 2,4–D and broadleaf plants are not. And, of course, there are many exceptions within the latter group of plants.

Many research workers in plant pathology would probably consider 2,4–D as a primary causal agent of physiological disease in plants. Some might dispute this concept on the basis of evidence that 2,4–D does not bring about "continued irritation" (a requisite of disease in plants according to Whetzel) (61), but rather, exerts only a single stimulus of short duration (injury) (15). There is, however, evidence to the contrary which suggests that the stimulus is of long duration (57).

Although the gross morphology of a grass may be greatly altered by 2,4–D, the question has arisen as to the occurrence of critical periods in the life cycle when susceptibility to injury is greatest and non-critical periods when no injury is incurred. Some convincing work on this important question has been contributed within the last several years (5, 7, 14, 21, 22, 23, 27, 30, 31, 33, 34, 41, 42, 46, 51, 52, 57). Most of these workers conclude that such critical periods do occur; e.g., in barley (14), there are four such periods: susceptible stages include seedlings (germination to expansion of the fifth leaf) and heading (preheading to late heading), and resistant or tolerant stages include the actively-growing vegetative plant (fifth leaf to boot stage) and the mature plant (post-heading); in corn (52), there are critical periods of short duration which appear to occur during morphologic development of the various parts of male and female floral apices (time of initiation and early development of the tassel, time of tassel emergence, and the period before silk emergence).

The influence of various factors on the expression and magnitude of responses of plants to 2,4–D treatment has been studied in considerable detail by various workers. It has been fairly clearly established that an increase in air temperature during and following 2,4–D treatment results in an increase in the expression and severity of morphological aberrations (9, 19, 26, 35). Other environmental factors, such as light intensity, relative humidity, and rainfall, have been discussed in detail (9, 19) and since they were not included in the rice investigations, the pertinent literature will not be reviewed in this paper. Higher concentrations of 2,4–D may, and usually do, enhance the expression and magnitude of morphological responses of 2,4–D susceptible plants; the literature which supports this fact is too voluminous to cite here. Plants treated at earlier stages of development may express more intense aberrations than when treated at later stages, but apparently this is not always the case (4, 14, 19, 51, 56, 57). Some internal factors are also important; e.g., relative absorption of various formulations of 2,4–D, the carbohydrate supply in leaves, the rate and direction of carbohydrate translocation (11, 12, 37, 40), and the type of tissue in which 2,4–D is active. Certain tissues and organs are more susceptible at certain stages of

development than others at concomitant time intervals (10, 15, 16, 17, 18, 52, 53, 58, 59). The molecular configuration of the synthetic hormone is also of importance (23, 28, 30, 31, 43, 54, 55). As a result of extensive tests, most European and American workers conclude that MCP is less injurious to cereals than 2,4–D and that esters of 2,4–D are more toxic to cereals than equivalent concentrations of the salts (11, 40).

To the writer's knowledge, the only published accounts of 2,4–D injury to the rice plant are those of Ryker and Brown (48), Ryker (47), Davis (13), Jones et al. (25), Ahlgren et al. (3), and Robbins et al. (44). The paper of Ryker and Brown (48) presents a detailed account of the injury, and most of the data presented below is derived from it. In essence, these workers reported and illustrated the following evidences of morphological injury: (1) darker green color of seedlings and older vegetative plants, (2) retardation in rate of growth of young plants, (3) swelling of the base of the shoot, (4) bending of stems at upper nodes, (5) inhibition of tillering, (6) emergence of large stubby roots from the base of the shoot, (7) improper emergence of panicles from the flag leaves with resultant deformation and reduction in size of the former, (8) blasting of florets, and (9) open hulls with abnormal reddish-brown grains.

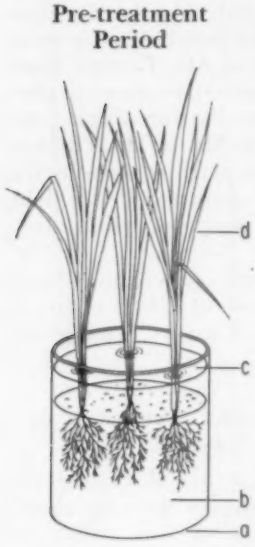
PROCEDURE

In order to obtain the most valid possible concept of the action of 2,4–D on the root and shoot systems of the rice plant, ontogenetic studies were conducted, utilizing as diverse a range of ecological conditions as possible. By employing the ontogenetic approach, the writer was able to investigate critically the time of inception and the sequence of events which led eventually to aberrations in the rice plant under field and greenhouse conditions. Some of the ecological variables considered included relative level of inorganic nitrogen supply in the soil, temperature of the water and air surrounding the rice plants, density of the population of rice plants, and depth of the water surrounding the plants. The treatment variables included type and amount of herbicide applied, time and method of application of the herbicide, and use of different varieties and stages of development of the rice plant.

Three general approaches were included in this investigation: (1) incubator and greenhouse studies, (2) field plot studies, and (3) commercial field studies. By using these three diverse types of studies, it became possible to analyze comprehensively the tremendous array of symptoms of the injury and some of the important influencing factors both under controlled and field conditions. A more detailed account of each of the three methods of approach to the problem is presented below.

The following diagram explains the nature of the greenhouse and incubator studies:

The techniques employed in conducting the field plot studies are summarized as follows: (1) three randomized replicates were sprayed daily from June 3 – Aug. 1, every other day from Aug. 2 – Aug. 16,



Herbicide Treatment Period

Observation Period

Greenhouse Environment	Incubator Environment	Greenhouse Environment
(a) One-gallon capacity container.	(a) 3-day time interval; treatment was made 48 hours after incubation; plants were returned to greenhouse 24 hours after treatment.	(a) Qualitative and quantitative gross morphological observations.
(b) Sacramento clay loam.	(b) Temperatures: 62, 72, 97° F.	(b) Microscopic dissection studies.
(c) 2 ± 0.5 inches of water above soil surface.	(c) Herbicide was applied as an aqueous spray (in most cases) with calibrated sprayer apparatus.	(c) Collection of material for anatomical studies.
(d) Ten rice plants/can. Different cultures were treated with herbicide from seedling to panicle emergence stages of development.		(d) Photographs of treated and control plants.

Diagram 1: Schematic Representation of the Greenhouse and Incubator Studies.

and every four days from Aug. 16 – Aug. 28, 1950; (2) each plot was treated at 8 a.m. with 24.0 ounces of 2,4–D acid equivalent per acre (triethanolamine salt) with calibrated spray apparatus; (3) the tem-

perature of the air and water was recorded daily for the duration of the experiment; (4) all plots were located in one half of a weed-free rectangular rice check at the rice ranch of Mr. George Lodi, located near Arbuckle, California; (5) randomized replicated plots were also established at the Rice Experiment Station during the same summer as well as during 1951 and 1952 by Mr. A. H. Williams.

With respect to the commercial field studies, gross morphological observations of thirty-seven 2,4–D treated and non-treated rice fields in five counties in the Sacramento Valley were made at definite time intervals after treatment.

Complete data[4] were obtained for each field; observations made after 2,4–D application included general surveys of 2,4–D injury in each field, analysis of the location and type of injury, and photographs of the various types of injury noted.

A SUMMARY OF MORPHOLOGICAL ABERRATIONS EXHIBITED BY RICE PLANTS TREATED WITH 2,4–D

Symptoms of 2,4–D injury to the rice plant are described and illustrated below so that the nature of this injury may be clearly understood when mentioned in later sections of this paper (on factors which influence the expression and magnitude of injury). The descriptions and illustrations are derived from the greenhouse and field studies described under Procedure. MCP may bring about most of the injury symptoms mentioned below, but since the injury symptoms induced by this herbicide, in the case of rice, have not been as completely studied, they will be described briefly in a later section of this paper.

Hyperplastic symptoms: "Those evidences of disease incident to excessive multiplication, overgrowth, or overdevelopment of cells are termed hyperplastic. These symptoms may be considered progressive" (60).

(1). Production of tubular or "onion" leaves (aberration index 8) – characterized as being solid or partially hollow and cylindrical in form for varying distances. Any of the leaves formed after 2,4–D treatment may be tubular, and one to several may appear in a treated plant. Tubular leaves are illustrated in Figure 1 (leaves 3, 4, 5 and 6).

(2). Cohesion of leaves – where sheaths of two leaves appear as one sheath and the two blades are irregularly "fused" longitudinally. With respect to the latter, the blades are usually oriented at right angles to each other so that the leaf appears to have two blades.

(3). Longitudinal folding of blades (aberration index 7) – a frequent symptom which usually appears before tubular leaves are evident (these folded leaves do not develop into tubular leaves), resulting from more rapid growth of the under side. The upper

[4]This included information on owner of field, cropping history, fertilizer use, names of important weeds, density and distribution of weed populations, height and density of rice stand, time of 2,4–D treatment, information on formulation and rates of application of 2,4–D, and direction of flight.

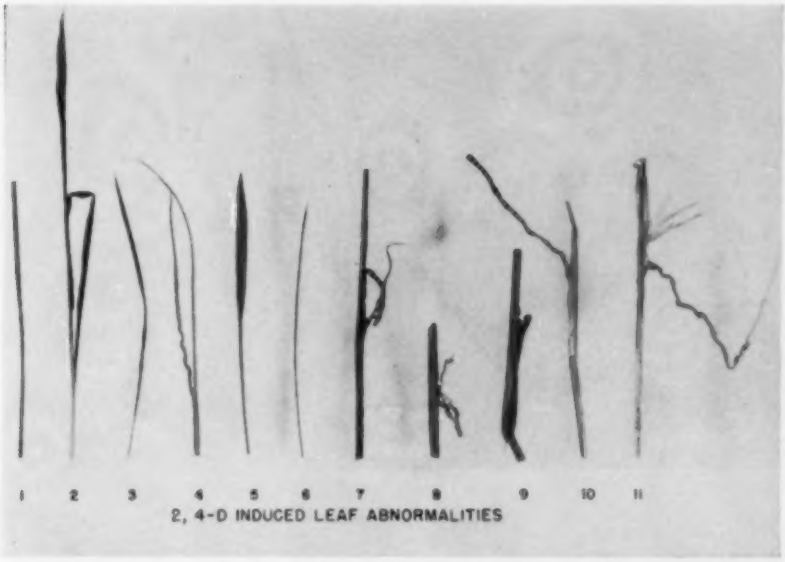


FIG. 1. Leaves representing the wide variety of aberrations which may result from 2,4–D treatment at herbicidal concentrations. These leaves were removed from plants in 2,4–D treated rice fields.

surface of the blade is thus concave to varying degrees. Folded leaves are illustrated in Figure 1 (leaves 1 and 2).

(4). Rapid changes in lamina position – characterized by accelerated rate of downward divergence of the blade from a nearly vertical position. It may take place within 24–48 hours after treatment, whereas normally, the process takes place over a much longer period. Only the fully open leaves in a vertical position respond in this manner. It is especially striking when plants are in the boot stage.

(5). Production of leaves with more intense or darker green color – exhibited by most 2,4–D treated rice plants when applications are made from pretillering to the boot stage of development. The symptom usually appears several days after treatment and persists up to the time of heading. Such leaves are also coarser in texture and thicker in diameter.

(6). Excessive elongation of leaves – especially noted in the case of later formed leaves (most noticeable is the flag leaf) when treatments are made from pretillering to the boot stage of development. Such leaves remain vertical longer than usual.

(7). Cohesion of stems – usually seen from the time of emergence to the time of maturation of the panicle and characterized by the "fusion" of one or more tiller stems to the stem of the main axis for variable lengths. The cohesion of the stems of a tiller and the main axis is illustrated in Figure 2.

(8). Excessive elongation of rachis internode of the panicle – a symptom most frequently seen in plants treated after the initiation

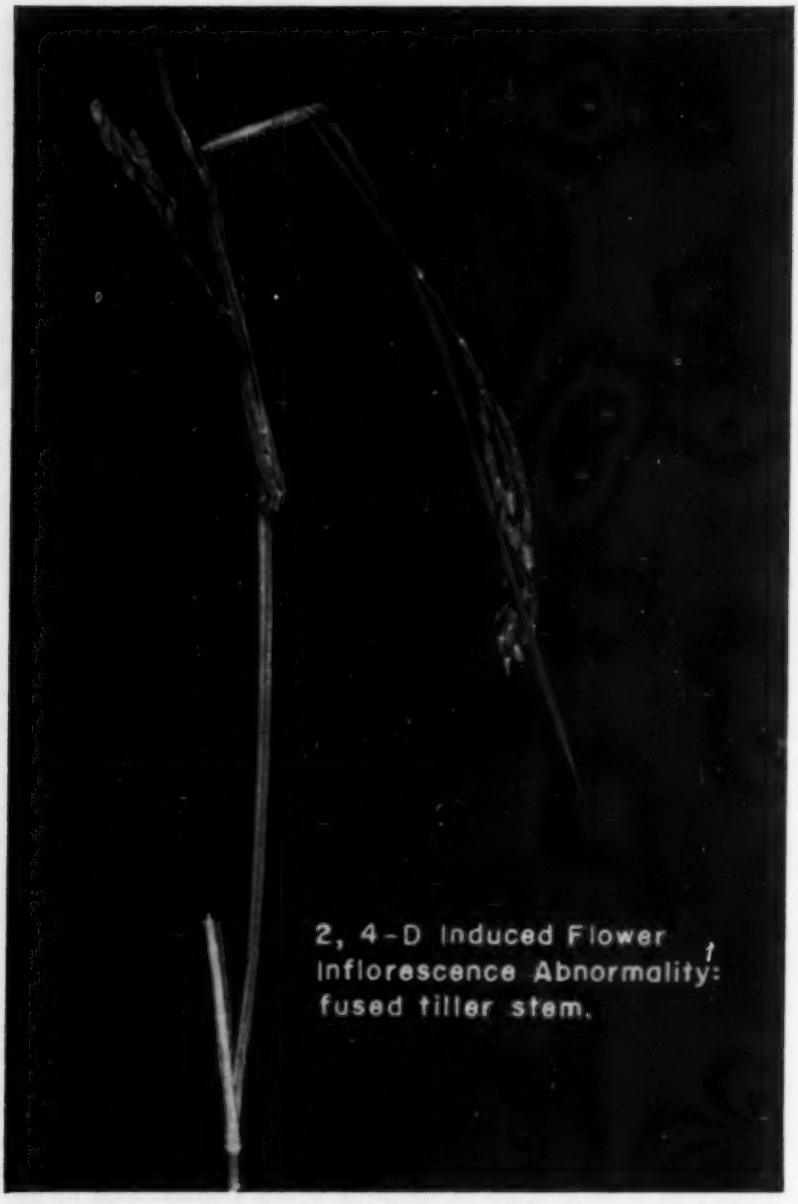


FIG. 2. Part of a nearly mature shoot in which one of the internodes of the stem of the main axis is joined longitudinally to a stem internode of a tiller shoot. This condition is sometimes referred to as "double-head" or "triple-head".

FIG. 3. Panicle at right shows one of the rachis internodes excessively elongated so that it diverges from the inflorescence. This is a common symptom of 2,4–D injury, becoming manifest as the panicles mature. A healthy panicle is shown at left.

of tillering. Such plants do not usually have any leaf aberrations. Figure 3 illustrates the symptom. In some 2,4–D treated rice fields, it may be one of the most easily discerned evidences of injury. Such panicles are also usually smaller than healthy ones and possess fewer grains.

(9). Excessive numbers of adventitious roots (aberration indices 4, 5, and 6) – a symptom consistently exhibited by plants treated from seedling to tillering stages of development. After early treatments, during a ten-twenty day period, these roots replace the seminal root system (which reaches senescence prematurely) and result in a coarser, more shallow root system composed of a larger number of roots than in the case of root systems of healthy plants. This sequence of events is illustrated in Figure 4. With later treatments, the phenomenon is not so striking, for the seminal root system, in these cases, has already disappeared, and many adventitious roots have already been initiated.

(10). Excessive thickness of adventitious roots – characteristic of the above-mentioned roots, in which case the diameter may be increased 1¼–2 times that of healthy roots.

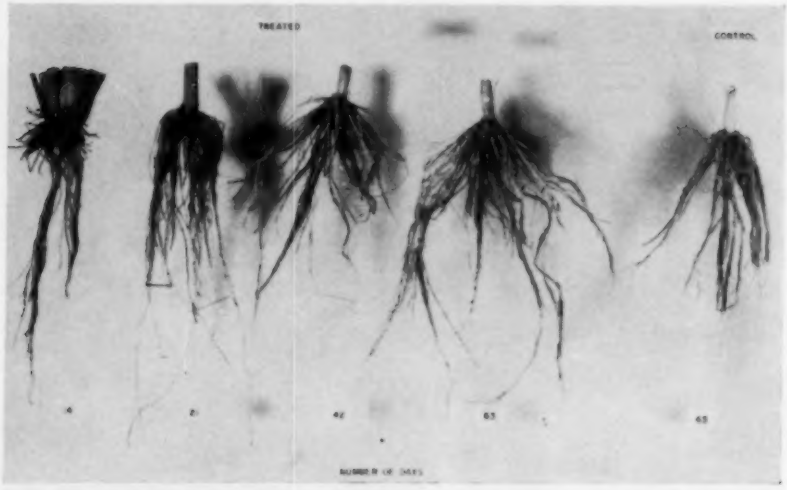


FIG. 4. Changes in the root system of the rice plant at various time intervals after 2,4–D treatment. The premature death of the seminal root system and the production of excessive numbers of adventitious roots is shown in the root system at far left (14 days after treatment). Note the larger adventitious root system of a treated plant 63 days after treatment than that shown by control plant of the same age. These plants were taken from a commercially sprayed rice field.

Hypoplastic symptoms: "Those evidences of disease incident to a halting in the multiplication, growth, and differentiation of cells and tissues are termed hypoplastic. They may also be considered as repressive" (60).

(1). Production of dwarfed leaves – a symptom which accompanies the root modifications shown in Fig. 4. Such leaves are shorter and narrower than those of healthy plants and give rise to the dwarfed appearance of the shoot system. This symptom becomes less noticeable and finally is no longer evident with successively later spraying dates.

(2). Retarded development of stems – one of the most characteristic symptoms of severely injured shoots. Stems so injured do not elongate normally and appear folded and twisted within tubular leaves (Figure 5). In some cases, where the enclosing leaf is not completely tubular, the cramped stem "buckles" out of this leaf and continues to elongate.

(3). Retarded or inhibited development of panicles, spikelets, and grains – occurring when plants are in the boot stage and afterwards. If aberrations of the vegetative plant are present, usually the heads will show varying degrees of injury. Observations of living vegetative shoot apices and floral apices with spikelet primordia indicate that they appear the same as in healthy plants. The partial or complete inhibition of development of already initiated panicles and their constituent parts takes place during the boot stage and as the head is developing after emergence. Most of the retarded develop-

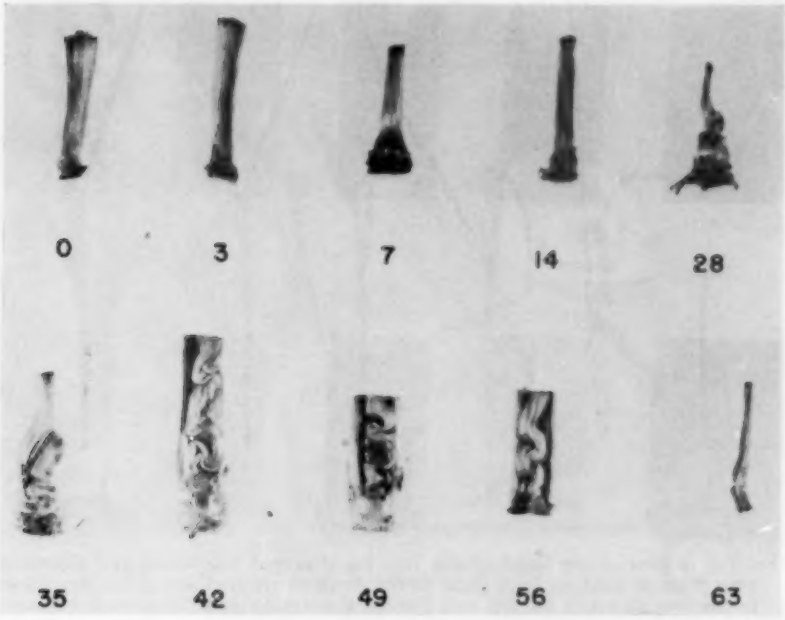


FIG. 5. Basal segments of the shoot system with some outer leaves removed to show symptoms of 2,4–D injury. Plants were removed from a single field plot at definite time intervals (indicated in days below each segment) after 2,4–D treatment. The predominant symptoms are twisting and folding of the inner developing leaves (28–63 days after treatment).

ment appears to be due to the abnormal development of the panicle just prior to and during emergence from the greatly distorted sheath of the flag leaf. This symptom is the one which is most consistently seen in 2,4–D injured rice fields. Various stages of the injury are illustrated in Figures 6 and 7. Entire panicles may be inhibited in further development because of failure to emerge from tubular leaves. More frequently, however, one sees heads with spikelets which were initiated but failed to continue developing (Figure 8). The cause of this inhibited development is yet unknown, but possibly meiotic aberrations are responsible (56, 57).

(4). Premature laxness of the panicle – usually associated with premature divergence of flag leaves. Sometimes such panicles reach senescence a week before healthy ones. One might consider this a hyperplastic symptom, but it is described here because of the shorter time during which the panicles mature and the suppression in ultimate size of such heads as a result of these shorter time intervals for development.

(5). Inhibited elongation of adventitious roots (aberration index 9) – takes place if treatments are made when tillering begins. It is clearly apparent that these roots are initiated in excessively large numbers, but they fail to elongate after they have attained a length

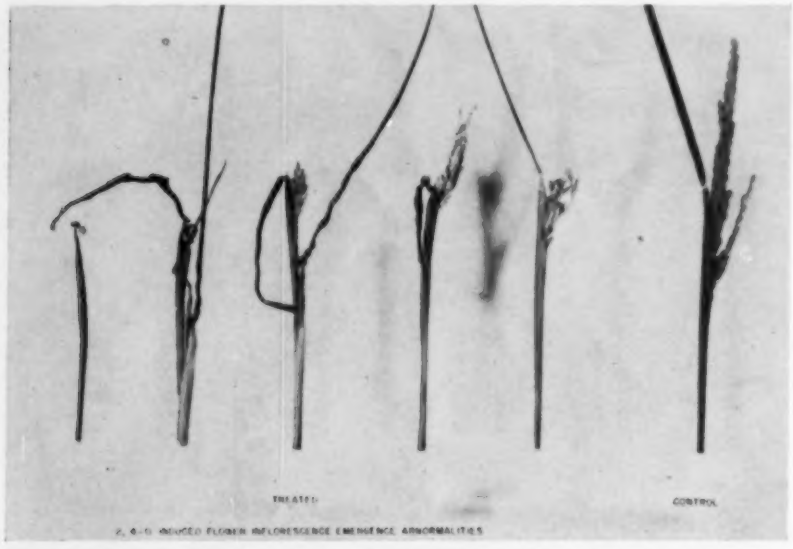


FIG. 6. Portions of the shoot system showing distorted flag leaves and abnormal emergence of panicles from these leaves. Panicles are enclosed in the flag leaves in the two shoots at the left and emerge abnormally and distorted in the next three. Plants were taken from field plots.

of several millimeters. They are much thicker than healthy adventitious roots.

(6). Secondary roots from adventitious roots – appearing near the apices of the latter and being much thinner. Their position and time of appearance are abnormal.

Necrotic symptoms: "Those evidences of disease that are incident to degeneration and death of cell protoplasts and tissues are termed necrotic. They must be considered as regressive" (60).

(1). Apical scorching of leaf blades – seen on leaf tips which at first are yellow several days after treatment, then become brown and dead. Such lesions frequently develop from top downward.

(2). Yellowing of leaves – a common symptom of actively growing vegetative plants in which leaf blades become yellow in localized areas (suggesting contact action of 2,4–D spray drops in addition to the translocation) 3–4 days after 2,4–D treatment. Many such leaves ultimately become entirely yellow and reach senescence much earlier than normally.

(3). Death of the vegetative shoot system (aberration index 10) – when tubular leaves are produced, the inner developing leaves undergo folding and distortion. If the pressure of these distorted growing leaves does not result in their emergence from partially or completely tubular leaves, the former begin to turn yellow, then brown, with ultimate death of not only these leaves but also the vegetative shoot apex (Fig. 5–63 days). In such cases, axillary buds are stimulated to develop into tillers so that more tillers, which are larger

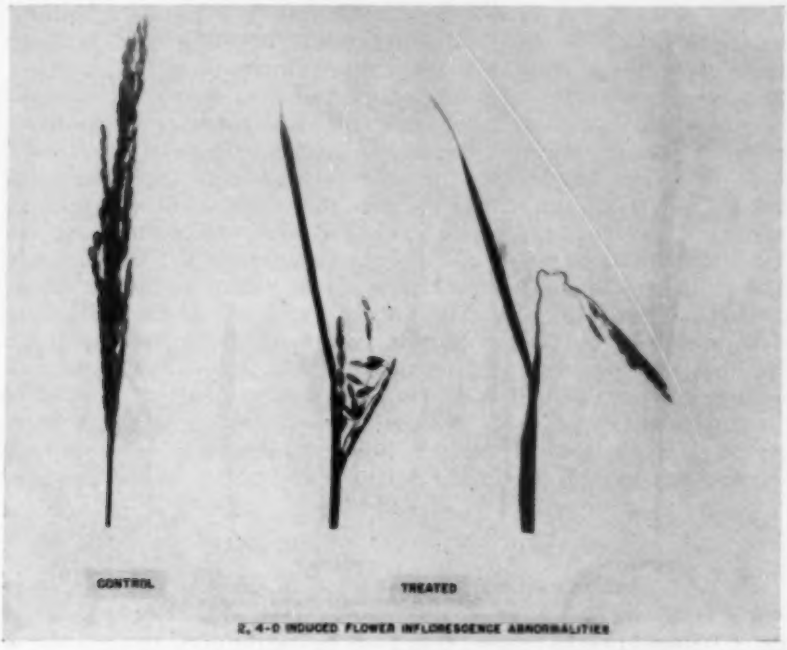


FIG. 7. Portions of the shoot system containing the inflorescence. Note the abnormal emergence of the second panicle. The panicle at the far right is abnormal as evidenced by the distorted rachis internodes and the diminished number of developing spikelets.

than normal, occur at the time of heading. When treatments are made on seedlings (2–4 weeks after transplanting from petri dish germination cultures), complete death of entire plants may result within 7–14 days (Figure 9).

(4). Death of part or all of the panicle – resulting from failure of development of part or all of the constituent parts of the panicle – perhaps due to failure of panicle emergence (tubular leaves) or something (perhaps meiotic aberrations) which inhibits panicle development during abnormal emergence from the flag leaf.

(5). Premature death of the seminal root system (aberration indices 1, 2, and 3) – always noted to start before the production of excessive numbers of adventitious roots. It is significant that by the time the adventitious root system begins to develop, most of the seminal root system is dead (Figure 4–14 days). In the healthy plant, the transition from seminal to adventitious root system is gradual and overlapping.

(6). Death of adventitious roots – characteristic of adventitious roots which have failed to elongate (cf. hypoplastic symptom 5 on p. 25).

Anatomical Symptoms: The histological events leading to the development of a number of the above mentioned symptoms have been

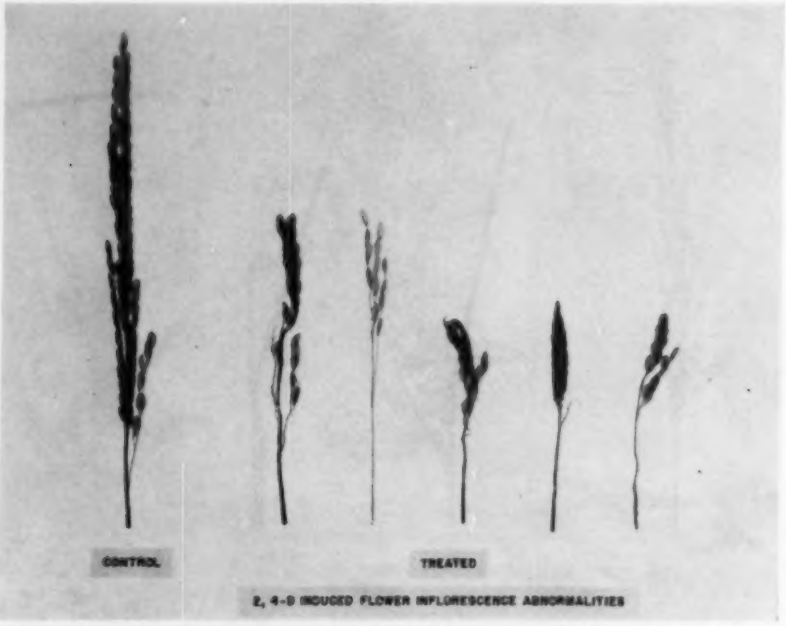


FIG. 8. Distorted panicles removed from 2,4–D treated rice fields. Characteristic of such "heads" are the few numbers of grains, the shortened internodes of the rachis, and the rudimentary spikelets which never developed.

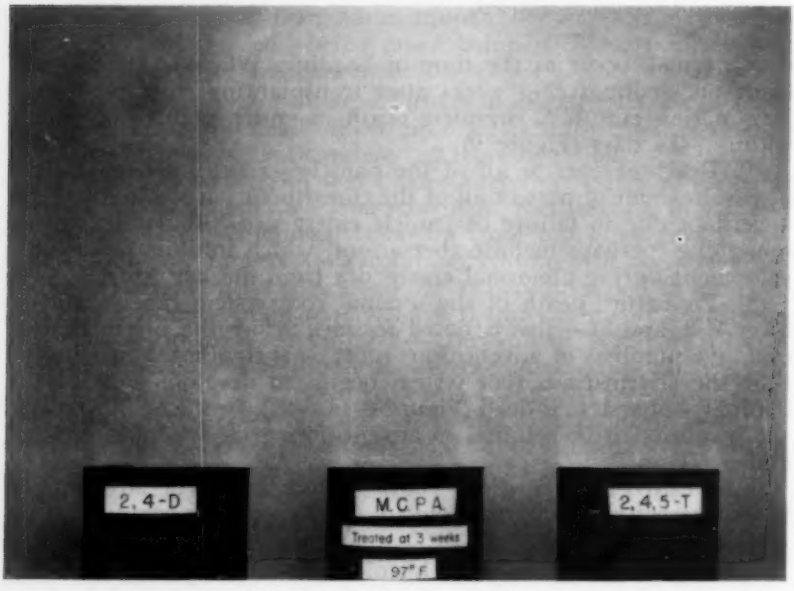


FIG. 9.

studied in detail, and the information will be presented in another paper. Some of the anatomical modifications of the shoot system include (1) distortion of the marginal meristem of the leaf, which appears to play a part in the development of tubular leaves; (2) tumor-like proliferation of the internodal regions of the stem and the sheath bases of the main shoot and tiller shoots as a result of stimulation of meristematic cells in the ground tissue in these regions; (3) stimulation of rib meristem in young internodes so that the latter are longer than in healthy plants; (4) production of excessive numbers of abnormally large adventitious roots in stem internodes at the periphery of the outer ring of vascular bundles (the roots themselves are gigantic in contrast to healthy adventitious roots, primarily due to proliferation of the early cortex); (5) early development of secondary roots from large adventitious root primordia at the periphery of the vascular system so that adventitious root masses frequently appear as three distinct proliferations; (6) development of tumor-like proliferations from elongating adventitious roots at the periphery of the vascular system of the latter.

Meanings of Aberration Indices[5]

1 = slight necrosis of pre-2,4–D treated root system.
2 = moderate necrosis of pre-2,4–D treated root system.
3 = extensive necrosis of pre-2,4–D treated root system.
4 = 2,4–D stimulated adventitious roots 1.5 – 3.0 mm. long.
5 = 2,4–D stimulated adventitious roots 3.0 – 38.0 mm. long.
6 = 2,4–D stimulated adventitious roots 38.0 mm. or longer.
7 = incipient stages of leaf aberrations: leaves emerge abnormally, and laminae are folded longitudinally to varying degrees.
8 = presence of tubular leaves in variable numbers.
9 = 2,4–D stimulated adventitious roots are inhibited in further development.
10 = complete death of entire plants.
11 = leaves of shoot system appear normal.
12 = roots of root system appear normal.

SOME OF THE FACTORS WHICH INFLUENCE THE EXPRESSION AND MAGNITUDE OF 2,4–D INJURY TO THE RICE PLANT

(a) The Role of Temperature

In greenhouse tests, the effect of temperature on the response of rice plants to 2,4–D was tested according to the scheme depicted in *Diagram 1* (p. 227). Data were obtained every two weeks for a period of two months after the treatment. One set of these data is presented in Table 1 on p. 238.

[5]Where aberration indices are bold face, this implies that the particular symptom is more intense than the others listed for a particular treatment.

Table 1. Quantitative and Qualitative Gross Morphological Data[6] On the Response of Rice Plants To Different Amounts of 2,4–D at Two Temperatures and Seven Stages of Development.

Treatment			Data			
Age of plants at treatment time (in days)	Ounces of 2,4-D (acid equivalent per acre)	Incubation temperature (degrees Fahrenheit)	Average height[7] (in centimeters)	Leaf color	Aberration indices[8]	Remarks
14	0	62	63.50	yellow-green	11, 12	Tubular leaf symptom is still most striking, but some plants appear to have recovered because of production of tiller shoots devoid of symptoms.
14	15	62	38.10	dark green	3, 6, 7, 8	
14	20	62	38.10	do.	do.	
14	25	62	35.56	do.	do.	
14	0	97	58.42	yellow-green	11, 12	
14	15	97	30.48	dark green	3, 6, 7, 8	
14	20	97	30.48	do.	do.	
14	25	97	33.02	do.	do.	
28	0	62	63.50	yellow-green	11, 12	Heights of shoots are markedly reduced in the high temperature series of treated plants. Tubular leaves are numerous in all of the 2,4-D treated cultures.
28	15	62	30.48	dark green	3, 6, 7, 8	
28	20	62	35.56	do.	do.	
28	25	62	33.02	do.	do.	
28	0	97	58.42	yellow-green	11, 12	
28	15	97	17.78	dark green	3, 6, 7, 8	
28	20	97	20.32	do.	do.	
28	25	97	20.32	do.	do.	
42	0	62	53.34	yellow-green	11, 12	Tubular leaf production and dearth of shoots is most striking in this series, especially at the higher temperature.
42	15	62	40.64	dark-green	3, 6, 7	
42	20	62	38.10	do.	3, 6, 7, 8	
42	25	62	40.64	do.	do.	
42	0	97	55.88	yellow-green	11, 12	
42	15	97	——	brown	10	
42	20	97	12.70	dark green	3, 6, 7, 8	
42	25	97	——	brown	10	
56	0	62	53.34	yellow-green	11, 12	Symptoms are more intense and height reduction is greater in the 97°+2,4-D treatment than the 62°+2,4-D treatment.
56	15	62	43.18	green	2, 6, 7	
56	20	62	45.72	do.	do.	
56	25	62	43.18	do.	do.	
56	0	97	58.42	yellow-green	11, 12	
56	15	97	33.02	dark green	2, 5, 7, 8	
56	20	97	33.02	do.	do.	
56	25	97	30.48	do.	do.	
70	0	62	53.34	yellow-green	11, 12	Symptoms of 2,4-D injury are not as striking in this series as in the one immediately above.
70	15	62	48.26	green	1, 4, 7, 8, 9	
70	20	62	48.26	do.	do.	
70	25	62	45.72	do.	do.	
70	0	97	55.88	yellow-green	11, 12	
70	15	97	40.64	do.	1, 4, 7, 8, 9	
70	20	97	40.64	do.	do.	
70	25	97	38.10	do.	do.	
84	0	62	55.88	yellow-green	11, 12	Few symptoms of 2,4-D injury occur in this series. There are essentially no variations in symptoms due to differences in temperatures.
84	15	62	50.80	do.	4, 9	
84	20	62	do.	do.	do.	
84	25	62	do.	do.	do.	
84	0	97	55.88	do.	11, 12	
84	15	97	50.80	do.	4, 7, 8, 9	
84	20	97	do.	do.	4, 9	
84	25	97	do.	do.	do.	
98	0	62	55.88	yellow-green	11, 12	Only incipient stages of adventitious root modifications are evident here in addition to the small reduction in height of shoots.
98	15	62	48.26	do.	4, 9	
98	20	62	do.	do.	do.	
98	25	62	do.	do.	do.	
98	0	97	53.34	do.	11, 12	
98	15	97	50.80	do.	4, 9	
98	20	97	do.	do.	do.	
98	25	97	do.	do.	do.	

[6]One month after treatment of 98 day old plants.
[7]Average of ten plants.
[8]Meanings of aberration indices are indicated on p. 237.

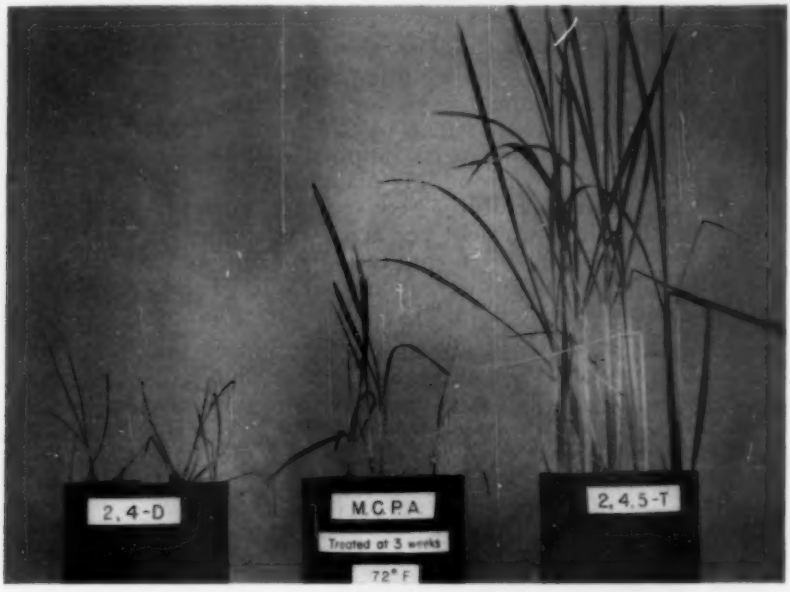


FIG. 10.

The following results were apparent: (1) symptoms of injury were consistently more intense when 2,4–D treatments were made at 97° F. on plants at the youngest stage of development; (2) plants treated from tillering to boot stages manifested few aberrations – only slight reduction in heights of shoots and some modification of adventitious roots; (3) plants treated four weeks after germination recovered late in development because of stimulated tiller production, but plants treated six and eight weeks after germination, for the most part, did not recover and produced very few panicles. The temperature effect is illustrated in Figures 9–16.

The data obtained from field plot tests during the summers of 1950 and 1951 also support the above observations. It was significant that in those fields and plots that were treated just prior to and during the high water temperature (maximum water temperature: 99–103° F.) period (June 28–July 3), the most striking aberrations were noted. Plants treated after this period (maximum water temperature: 77–98° F.) showed few aberrations up to the boot stage. During the summer of 1951, when field trials with 2,4–D, MCP, and 2,4,5–T were made, few if any aberrations were noted. The maximum temperatures were relatively low during that season. In the summer of 1952, when summer temperatures were again high (exceeding 100° F. maximum for various periods), field injury was again extensive. From all the field, plot, and greenhouse studies, it appears rather conclusive that air and water temperatures play a significant role in the physiological and morphological responses of the rice plant to 2,4–D.

(b) The Role of Nitrogenous Fertilizer

An experiment, carried out in the same way as described under temperature studies, was set up to determine if additional nitrogen in the soil had any influence on the expression of 2,4–D induced injury in shoot and root systems of rice plants. The fertilizer used was $(NH_4)_2SO_4$ (20.8% nitrogen), applied at the rate of 200 pounds per acre to the water surrounding plants fifty days old. Some 2,4–D treated and control cultures received no fertilizer. 2,4–D (20.0 ounces 2,4–D acid equivalent per acre) was applied 28 days before and at the time of fertilizer application (22 and 50 days after seed germination). Some plants were incubated at 62° F. and 97° F. at the time of treatment; others 14, 21, and 28 days after treatment. Data obtained in this experiment are summarized in Table 2 below.

Table 2. Quantitative and Qualitative Gross Morphological Data[9] On the Response of Rice Plants to Ammonium Sulfate and 2,4–D at Two Temperatures and Two Stages of Development.

Treatment				Data		
Fertilizer treatment	2,4-D Treatment (days after germination)	Incubation time (days after 2,4-D treatment)	Incubation temperature (degrees Fahrenheit)	Average height[10] in centimeters	Leaf color	Aberration indices[11]
$(NH_4)_2SO_4$	2,4-D-22	14	62	35.56	dark green	2, 5, 7, **8**
none	2,4-D-22	14	62	25.54	yellow-green	2, 5, 7, 9
none	none	14	62	53.34	green	11, 12
$(NH_4)_2SO_4$	2,4-D-22	14	97	——	brown	10
none	2,4-D-22	14	97	30.48	yellow-green	2, 5, 7, 8
none	none	14	97	38.10	do.	11, 12
$(NH_4)_2SO_4$	2,4-D-22	21	62	27.94	dark green	2, 5, 7, 8
none	2,4-D-22	21	62	25.40	green	2, 5, 7
none	none	21	62	53.34	do.	11, 12
$(NH_4)_2SO_4$	2,4-D-22	21	97	25.54	yellow-green	2, 4, 7, 8
none	2,4-D-22	21	97	25.54	do.	2, 5, 7, 8
none	none	21	97	40.64	do.	11, 12
$(NH_4)_2SO_4$	2,4-D-22	28	62	30.48	dark green	3, 5, 7, **8**
none	2,4-D-22	28	62	27.94	green	3, 5, 7
none	none	28	62	53.34	do.	11, 12
$(NH_4)_2SO_4$	2,4-D-22	28	97	25.40	do.	3, 5, 7, **8**
none	2,4-D-22	28	97	25.40	do.	3, 5, 7, 8
none	none	28	97	53.34	do.	11, 12
$(NH_4)_2SO_4$	2,4-D-50	14	62	58.42	green	1, 4, 11
none	2,4-D-50	14	62	50.80	yellow-green	1, 4, 11
none	none	14	62	53.34	do.	11, 12
$(NH_4)_2SO_4$	2,4-D-50	14	97	58.42	green	1, 4, 11
none	2,4-D-50	14	97	50.80	yellow-green	1, 4, 11
none	none	14	97	53.34	do.	11, 12
$(NH_4)_2SO_4$	2,4-D-50	21	62	58.42	green	1, 4, 11
none	2,4-D-50	21	62	50.80	yellow-green	1, 4, 11
none	none	21	62	53.34	do.	11, 12
$(NH_4)_2SO_4$	2,4-D-50	21	97	58.42	green	1, 4, 11
none	2,4-D-50	21	97	50.80	yellow-green	1, 4, 11
none	none	21	97	53.34	do.	11, 12
$(NH_4)_2SO_4$	2,4-D-50	28	62	58.42	green	1, 4, 11
none	2,4-D-50	28	62	50.80	yellow-green	1, 4, 11
none	none	28	62	53.34	do.	11, 12
$(NH_4)_2SO_4$	2,4-D-50	28	97	58.42	green	1, 4, 11
none	2,4-D-50	28	97	50.80	yellow-green	1, 4, 11
none	none	28	97	53.34	do.	11, 12

[9]Twenty days after last 2,4-D treatment.
[10]Average of ten plants.
[11]Meanings of aberration indices are indicated on P. 237.

The following results were evident: (1) when 2,4–D was applied to rice plants at an early stage of development (22 days after germination), the heights of the shoots were markedly reduced at both temperatures, but this did not occur with the later 2,4–D treatment (50 days after germination); (2) in cultures where $(NH_4)_2SO_4$ was added and 2,4–D had already been applied, the heights of shoots were increased, but where no fertilizer was added, ultimate shoot height was reduced by 2,4–D in comparison with controls; (3) from all the data collected, it was evident that $(NH_4)_2SO_4$ brings about a marked increase in the rate of growth of shoots of 2,4–D treated plants, that if applied after 2,4–D treatment, the intensity of the aberrations induced by 2,4–D increased slightly, but if applied at the time of 2,4–D treatment, no increase occurred; (4) it appears, from these experiments, that the temperature and stage of growth factors are much more influential in altering the intensity of 2,4–D induced aberrations than the fertilizer treatment. Field data also tend to support this conclusion, for an accurate record was made of nitrogen fertilizer applications made at preplanting, prespraying, and spraying (2,4–D spraying) dates in different rice fields, and no correlation was found between fertilizer application and effect of 2,4–D on rice.

(c) The Role of Density Variations in Rice Populations

Careful observations of variations in density of stands of rice in different parts of commercial fields were made during all field inspections of 2,4–D treated fields. These included density studies both prior to and following 2,4–D treatment. It was consistently noted that the most severe symptoms of 2,4–D injury appeared in the thin stands of rice and along margins of checks where the stand density is usually greatly reduced. In some fields with very dense populations, few or no injury symptoms could be found, whereas thin stands in adjacent fields, treated at the same time with 2,4–D, would usually show much more injury. Explanations for this might be that (1) the dense stands kept water temperature lower than thin stands (by virtue of shading and absorption of thermal radiation by rice plants); (2) less 2,4–D was absorbed per plant in the dense stands than in thin stands (more 2,4–D might possibly enter the root system via the water in thin stands); or (3) plants growing in deep water or thin stands were delayed in development and were thus perhaps more susceptible to 2,4–D injury (cf. section d). This observation was not studied under controlled conditions in the greenhouse; in view of the fact that marked field differences were noted, it appears that this factor should be subjected to critical tests under controlled conditions.

(d) The Role of Stage of Development of the Rice Plant

Extensive investigations were conducted on the responses of rice plants at different stages of development to 2,4–D both in the greenhouse and in the field. All greenhouse tests set up to study the influence of other factors included treatments at different time intervals. The field plot trials of 1950 included daily replicated treatments

for the duration of three months. Commercially sprayed fields were also treated at different stages of development – due to different planting dates and spraying dates.[12] Data obtained in the greenhouse test are presented in Table 1.

From data accumulated from each of these types of treatments, the following responses were evident: (1) plants treated up to several weeks after germination (0–4 weeks) may be killed completely by herbicidal concentrations applied during a high temperature period (Fig. 9); (2) plants which survive herbicidal treatments made in the pretillering stage of development (and including early stages of tiller development) manifest the most severe injury symptoms, particularly if treatments are made at high temperatures (Figs. 9–12); (3) greenhouse, field plot, and commercial field tests over a three year period show conclusively that injury to the rice plant, accentuated by high temperatures, occurs at the pretillering, boot, and panicle emergence stages of development, and that injury occurring during all three periods may result in varying amounts of reduction in yield; (4) plants treated from the tillering to the boot stages usually show few or no injury symptoms (Figs. 13–16); exceptions have been occasionally noted in field plots, but the injury is not usually striking.

(e) The Responses of Different Varieties of Rice

To determine possible differences in the responses of some of the commercially important varieties of rice to 2,4–D, an extensive experiment was set up in the greenhouse, using different stages of development and two temperatures (72° F. and 97° F.) for each of the herbicidal treatments. In this experiment, the 2,4–D (triethanolamine salt) was introduced into the water surrounding the rice plants at 2000 ppm in 20 ml. aliquots. The varieties tested included Caloro, Colusa (1600), Calrose, Zenith, Early Prolific, Lady Wright, Cody, and Late Slender.[13]

The following information was obtained from this experiment: (1) all varieties were most severely injured when 2,4–D applications were made at the high temperature, when the plants were at a young stage of development; (2) observations of varietal response to 2,4–D applications made at the various stages of growth (seedling to boot stage) indicated that no marked varietal differences could be seen; symptoms, both in terms of type and frequency of occurrence, were consistently similar in each of the varieties for each 2,4–D treatment. Unfortunately the experiment did not include treatments during panicle emergence stages; thus, the similarity of responses indicated above applies only to treatments made up to the boot stage. Field evidence indicates also that the responses of the varieties, Caloro, Colusa, and Calrose, to 2,4–D are similar.

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[12]Spraying dates varied from 41–78 days after planting in over thirty observed fields in five counties.

[13]Late Slender is a long grain selection from experimental stock that is similar in type to the long grain varieties grown in Southeastern United States.

(f) The Effect of Method of Application and Water Level

It was of interest to learn (1) whether 2,4–D caused more intense injury if applied through the leaves only or through the water, and (2), to learn whether more or less injury occurred when field spraying was done on drained checks in comparison with the usual spraying of flooded checks. The first problem was investigated in the greenhouse. Rice plant were treated at one and two months after germination at 62° F. and 97° F. with 2,4–D, at 2000 and 4000 ppm, applied to the leaves only (15 ml.) and the water only (15 ml.). The second problem was not included in the commercial application tests because of the difficulty of draining entire checks or fields for such tests. But variations in depth of water in different sections of given rice fields were noted at the time of spraying (3 to 24 inches), and observation of responses in areas of different water level were noted. Of course, it is evident that field tests should be conducted on the presence and absence of water during and following 2,4–D application because there is some evidence that the absence of water at the time of spraying, as well as just before and after spraying with 2,4–D, may be one of the factors which enhances both the susceptibility of rice plants to 2,4–D and the absorption of this chemical by rice plants.

Table 3. Quantitative and Qualitative Gross Morphological Data[14] on the Responses of Rice Plants to 2,4–D Applied To the Water Only and the Leaves Only at Two Temperatures and Two Concentrations.

Treatment		Data				
Method of Application	2,4-D concentration (ppm)	Incubation temperature (degrees Fahrenheit)	Average height[15] (in centimeters)	Leaf color	Aberration indices[16]	Remarks
Leaves only	2000	62	35.56	yellow-green	2, 9	In cultures where 2,4-D was placed in the water only, leaves and shoot bases exhibited more intense symptoms (death of tissues) than when leaves only were treated.
Leaves only	4000	62	35.56	do.	2, 9	
Water only	2000	62	25.40	brown	3, 9	
Water only	4000	62	25.40	do.	3, 9	
Leaves only	2000	97	35.56	yellow-green	2, 9	
Leaves only	4000	97	35.56	do.	2, 9	
Water only	2000	97	22.77	brown	3, 9	
Water only	4000	97	22.77	do.	3, 9	

[14]Fifteen days after 2,4-D treatment.
[15]Average of ten plants.
[16]Meanings of aberration indices are indicated on p. 237.

In the greenhouse tests (see Table 3 above), it was quite evident that plants were more susceptible to injury when treated at the higher temperature with the 2,4–D being placed in the water only. Differences in amount of 2,4–D applied did not alter the magnitude of the injury symptoms. It might be argued that more 2,4–D actually entered the plants through the water (roots and shoot bases) than through the leaves, and this might be responsible for the above differences; also, the translocation distance to highly susceptible regions (stem internodes, leaf primordia, and elongating leaves) is probably not as great in the former case.

FIG. 11.

Field observations indicated that no marked differences in the response of rice plants to 2,4–D could be discerned when applications had been made in areas having different levels of water (within the limits of 3 to 24 inches) at the time of and after 2,4–D treatment.

(g) The Effect of Differences in Amount of 2,4–D

Since amount of 2,4–D per acre is a variable which can be easily altered, it was of interest to learn whether there might be any differences in the response of rice plants to various amounts of 2,4–D. Investigations of this factor were made in commercial field trials, field plots, and greenhouse tests. In the first, amounts varied from 10–24 ounces of 2,4–D acid equivalent per acre (the triethanolamine salt being used in most cases); in the second, 24 and 48 ounces 2,4–D acid equivalent per acre; and in the third, 10–25 ounces of 2,4–D acid equivalent per acre.

In all of the greenhouse tests where concentration was a variable (see Table 1), no differences in type or frequency of occurrence of aberrations could be attributed to variations in concentration of 2,4–D. It might be argued that the range of concentrations used was too narrow and should be extended to limits < 10 and > 25 ounces of 2,4–D acid equivalent per acre. Some field evidence would indicate that this should be done (see statements below regarding field plot tests). In commercial field tests, most 2,4–D was applied at the rate of about 20 ounces of 2,4–D acid equivalent per acre. Periodic observations were made in fields receiving such applications as well as in those receiving 10 and 15 ounces 2,4–D acid equivalent per acre.

FIG. 12.

The fields were located in the same rice-growing area of Northern California but in different counties. Since such wide separation in fields was the case, the data obtained cannot be accurately compared. Observations in these fields indicated no differences in responses of rice plants to variations in concentration of 2,4–D applied. In the 1950 field plots at the Biggs Rice Experiment Station, weekly applications of 2,4–D at 24 and 48 ounces of 2,4–D acid equivalent per acre were made on randomized replicated plots. Observations during that season definitely indicated that 48 ounces induced a greater amount of injury to rice plants than 24 ounces (in terms of type and frequency of occurrence of aberrations), especially when applications were made during the high temperature period.

On the basis of the above evidence, it is apparent that further tests should be conducted on varying the amount of 2,4–D applied. One question that should be asked is this: are there any differences in the responses of rice plants to amount of 2,4–D in the range between 10–25 ounces 2,4–D acid equivalent per acre? This range corresponds to that used in commercial field applications in California.

(h) The Effect of Differences In Type of Herbicide Applied

With the effects on plant development and yield obtained from the use of 2,4–D as an herbicide in rice fields, it was important to find other possible herbicides that would be more selective on rice, and at the same time, effectively kill aquatic weeds. MCP was chosen because information, derived from work in Europe (11), suggested that this compound, when compared with equivalent amounts of

FIG. 13.

2,4–D, is less toxic to cereal plants than 2,4–D. 2,4,5–T was also used, for we had received information from other workers that it was more selective in cereals than 2,4–D.

The triethanolamine salts of 2,4–D, 2,4,5–T and MCP were used in greenhouse and field experiments. In the greenhouse tests, these chemicals were applied to eight varieties of rice at five different stages of development at 72° F. and 97° F., using 20 ounces acid equivalent per acre in each case. In the field experiments, randomized replicated plots and strips in commercial fields were treated with 2,4–D, 2,4,5–T, and MCP at 24 ounces acid equivalent per acre during the summers of 1951 and 1952. Esters of these herbicides were also used in the plots at the Biggs Rice Experiment Station.

The striking responses of the rice plant observed in the greenhouse tests are illustrated in Figures 9–16. The number of plants in each culture was the same at the time of treatment. Some of the more conspicuous responses include (1) complete death of rice plants when treated with 2,4–D, 2,4,5–T, and MCP at 97° F. at the age of three weeks; (2) the three chemicals cause more injury at 97° F. than at 72° F.; (3) the injury is more intense when plants are treated at an early stage of development than at later stages; (4) the order of toxicity is consistently 2,4–D > MCP > 2,4,5–T. All varieties of rice tested (the same as those mentioned on p. 242) responded to the treatments essentially in the same manner. Having made these tests, it was obvious that they should be extended to field plots and commercial fields; the results of such tests are described below.

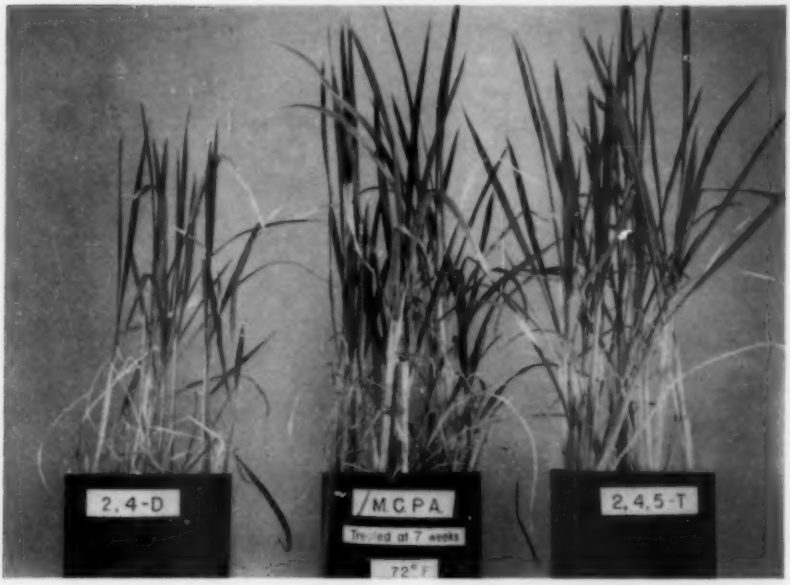

FIG. 14.

In both field plots and commercial field tests, the order of injury (greatest to least) to rice was 2,4–D > MCP > 2,4,5–T, and the percentage weed control (greatest to least) was (2,4–D = MCP) > (2,4,5–T). The predominant weed species were arrowhead *(Saggitaria* spp.) burhead *(Echinodorus cordifolius* (L.) Griseb.), and water plantain *(Alisma Plantago* L.). Where weed populations were fairly dense, 2,4–D and MCP controlled about 90% of the existing plants and 2,4,5–T about 10–50%. In most cases 2,4,5–T caused little or no injury to the rice. During the cool summer of 1951, MCP and 2,4–D caused some injury to treated plots and strips, but not to the extent seen in the greenhouse tests (early treatments). All plot and commercial field work indicate that MCP causes less injury to rice than 2,4–D and achieves essentially the same degree of aquatic weed control as 2,4–D.

DISCUSSION

It has been conclusively shown that the gross morphology and the anatomy of cereals can be markedly altered by herbicidal treatments with synthetic plant growth regulators. Many physiological studies demonstrate that this is the result of changes in the metabolism of treated plants. In rice, 2,4–D may bring about very striking changes in the structure of the root system, stem, leaves, and inflorescence.

As in the case of other grasses which have been treated with 2,4–D, rice has certain periods in its life history when it is relatively susceptible to injury and other periods when it is relatively resistant.

FIG. 15.

These periods, as also noted by Klingman for *Zea Mays* L. (27), correspond to periods when young meristematic tissues are developing. In the rice plant, it has been consistently noted that the apical meristem (vegetative and floral shoot apices) is not altered morphologically, but that leaf primordia, young leaves, axillary buds, the seminal root system, adventitious roots, stem internodes, and flower inflorescences in early stages of development are markedly changed in their morphology. These organs have meristematic tissues in which cells are actively dividing, enlarging, and undergoing active physiological and morphological differentiation. The time of development of these organs and their meristematic tissues corresponds to certain periods in the development of rice when the plant is relatively susceptible to 2,4–D injury. These periods include (1) seedling stage to tillering stage (when the plant possesses a vegetative shoot apex, axillary buds have not yet actively elongated into tiller shoots, and leaf and adventitious root initiation and development are the predominant gross morphological activities), (2) the boot stage (when the young panicle is enclosed in the flag leaf), and (3) the flowering stage (including panicle emergence, anthesis, and development of the ovaries).

The prevalent supposition that grasses are resistant to 2,4–D and broad-leaf plants are susceptible has been demonstrated to be fallaceous. In fact, we have learned that many grasses are highly susceptible to injury and that many so-called broad-leaf plants are resistant. We must also take into account the fact that many factors pertaining to the environment, the herbicide applied, and the plants

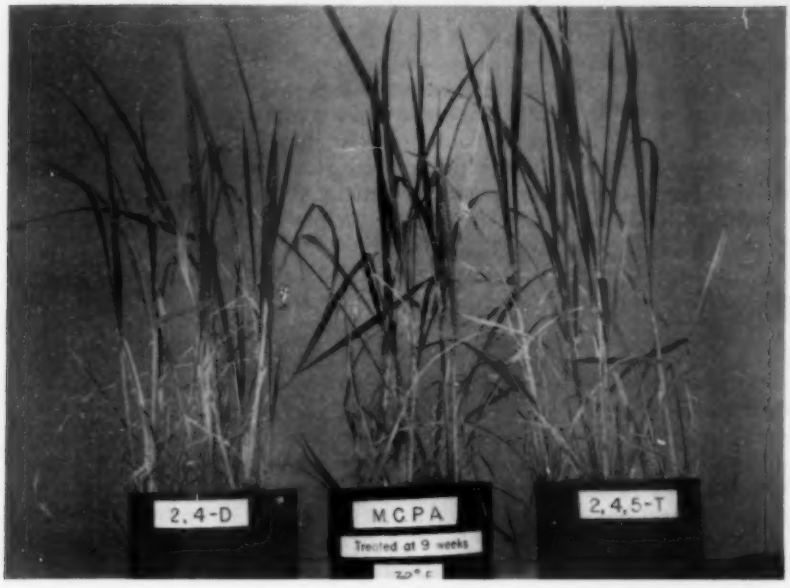

FIG. 16.

sprayed may markedly influence the relative susceptibility or resistance of the plant to the herbicide applied. In the case of the rice plant, such factors as air and water temperatures, density of rice populations, method of application, amount of 2,4–D, and stage of development of the plant in relation to time of treatment all appear to influence the relative susceptibility of the rice plant to 2,4–D. This evidence, as well as that obtained from studies on other small grains, definitely indicates that not all grasses are resistant to 2,4–D and suggests that perhaps other grasses may have susceptible periods. It appears to the writer that studies on relative susceptibility or resistance of plants to 2,4–D should allow for consideration of the above-mentioned factors in order to secure a more valid picture of plant responses. The numerous tables now published on plants resistant and susceptible to 2,4–D do have great value, however, in that they present a relative picture of the responses of various plants to 2,4–D applied at herbicidal concentrations. But it should be emphasized that many of these data could be more accurate and perhaps more useful if they were reanalyzed and subjected to testing in which many of the above-mentioned factors were altered. Such studies would probably give us a much better idea of certain selectivities and what to expect under field conditions.

After three years of field and greenhouse research, field recommendations for 2,4–D spraying of California rice fields have been made, with the aim of achieving the most effective weed control and the least possible injury to the rice. These include, (1) planting the rice as early as possible, (2) sowing seed evenly at heavy rates, (3)

fertilizing the rice early to promote early tillering and a dense stand, (4) keeping the water level as high as possible just before and after spraying, (5) making the spray application just before the most extensive aquatic weeds in the field begin to flower (in other words to spray as late as possible and yet achieve satisfactory control), (6) spraying only where serious weed problems exist in the rice field and avoiding the spraying of thin stands of rice if a weed problem does not exist in such areas, (7) spraying during a cool period (this is not always possible to anticipate) if such a period is found to coincide with requisite (5) above, and (8) using a salt of 2–methyl–4–chlorophenoxyacetic acid in preference to 2,4–D at as low a dosage as possible (15–25 ounces acid equivalent per acre).

SUMMARY

An extensive investigation of the gross morphological responses of the rice plant to 2,4–D under various ecological and physiological conditions has been described. The conclusions made below are based on extensive field, plot, and greenhouse tests conducted over a three year period. The morphological responses are heterogeneous and complex and have been treated as pathological symptoms. The data presented indicate that the rice plant may be highly susceptible to injury as a result of 2,4–D treatments. This susceptibility is relative and is greatest during periods of high temperature when rice plants are treated at early stages of development. During the development of the rice plant, there are several so-called sensitive periods when resistance to injury is low; these include the early seedling, tillering, boot, and panicle emergence stages. These stages correspond to periods when meristematic tissues -- in stem internodes, axillary buds, root and leaf primordia, enlarging leaves and roots, panicle primordia, and enlarging parts of the panicle – are extremely active. It is highly probable that it is in these tissues, where cell division and enlargement are so conspicuous, that 2,4–D is most active physiologically. Of the three synthetic plant growth regulators tested, 2,4–D was the most active, followed in turn by MCP and 2,4,5–T.

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Methods for Determining Relative Volatility of Esters of 2,4–D and Other Growth Regulants Based on Response of Tomato Plants*

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Renewed interest in volatility of hormone-like compounds has occurred since government restrictions were placed on the sale of certain esters used for herbicidal purposes. After crop plants neighboring on fields sprayed with volatile herbicides were injured, attempts were made to find low volatile esters which could be used with greater safety. This was done by making long chain esters containing five or more carbon atoms. Since many of these are now being made, the problem is to find satisfactory test methods for determining the relative volatility as compared with known compounds and standard formulations.

The volatility of hormone-like substances was reported as early as 1939 by Zimmerman, Hitchcock, and Wilcoxon (6, 9) and again in 1942 in the first publication on 2,4–dichlorophenoxyacetic acid (2,4–D) and other substituted phenoxy compounds (7). In these tests the ester was placed together with the test plant under a bell jar for periods of one hour or longer.

About 1949 Marth and Mitchell (3), Mullison and Hummer (4), Tafuro *et al.* (5), and Allen (1) reported on volatility of esters and other derivatives of 2,4–D. King and Kramer (2) later reported on the volatility of polyethylene and polypropylene glycol esters of 2,4–D and 2,4,5–trichlorophenoxyacetic acid (2,4,5–T). Methods of detecting contamination of volatile material were recently described in an article by Zimmerman *et al.* (8).

The present report shows how methods can be placed on a quantitative basis for amounts of the esters used and the degree of responses induced on tomato plants. Several different methods are compared and their values discussed. A more detailed report of this work was published by Hitchcock *et al.* (1 A).

Materials and Methods

Tomato plants 2.5 to 3 inches in height were found to be the most sensitive for testing volatile substances. At this size the plants were 25 to 28 days old from seed.

Both pure chemicals and commercial formulations were tested. Unless otherwise stated, all of the formulations contained the equivalent of 4 lbs. of acid per gallon. Tables 5 and 6 include a list of some of the formulations tested.

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During the course of the investigations several techniques were used and compared. The principal containers were bell jars, vinylite bags, and paper bags. The paper bag was selected for the standard application technique. The method involved enclosing a single plant at the bottom of a fully opened 20 lb. paper bag together with a 7 cm. diameter filter paper moistened with a known amount of the formulation. The filter paper was placed at the bottom of the bag, not touching the side of the bag, the pot, or any part of the plant. The upright bag was sealed at the top by folding over two layers of paper and fastening with paper clips (Fig. 1 A). After bags were closed, they were placed at the desired temperature and left for time periods of 1 to 24 hours. The formulations were applied to the filter paper by means of pipettes or platinum bacteriological loops. In most of the tests a 0.01 ml. loop was used.

The evaluation of results was based on responses such as epinasty of leaves, curvature of stems, proliferation, modification of leaves, and inhibition of growth. The initial responses (curvatures) were evaluated within 24 hours after the treatment and the others 7 to 10 days later. Leaf modification and proliferation of stems were each estimated on the basis of a magnitude of response scale ranging from 5 (minimum) to 40 (maximum). Only slight proliferation occurred on plants which exhibited pronounced modification. Increasingly higher doses of the chemical caused an increase in the magnitude of proliferation but no modification due to the lack of growth. An isopropyl ester formulation of 2,4–D was used as a high volatile substance and a propylene glycol butyl ether ester formulation of 2,4–D as a low volatile substance.

RESULTS

Effect of concentrations. The magnitude of the response increased with the concentration of the formulations and the volatility of the chemicals. Table 1 shows the difference between a high and a low volatile ester. It also shows that the difference is greater at high than at low concentrations. For example, the isopropyl ester at the highest concentration induced stem proliferation, but the low volatile propylene butyl ether ester did not. Also the responses increased with

Table 1. Effect of concentration and duration of exposure on relative magnitude of responses of plants 10 days after treatment with 0.01 ml. of 2,4–D.

Concentration, %	Responses to isopropyl ester					Responses to propylene glycol butyl ether ester	
	4-Hour exposure*		24-Hour exposure			24-Hour exposure*	
	Av. height increase, cm.	Modification	Av. height increase, cm.	Modification	Proliferation	Av. height increase, cm.	Modification
0.00	13	0	8	0	0	9	0
0.01	12	0	10	0	0	8	5
0.10	13	0	10	5	0	10	10
1.00	13	5	9	25	0	9	10
10.00	14	25	9	40	0	10	20
48.00	12	35	4	0	35	10	40

*No proliferation induced by this treatment.

length of exposure to the substances. For example, the high volatile ester at 0.10 per cent did not cause a response on plants with a 4-hour exposure but caused modification of leaves with the 24-hour exposure.

The effect of the amount of formulation used. There was an increase in response with an increase in the amount of the formulation used for the exposure (Fig. 1 B and C). Table 2 shows the differences between high and low volatile ester formulations when different amounts were used. For example, when 0.1 ml. was used, the high volatile isopropyl ester induced pronounced proliferation and no modification, but the low volatile ester induced slight proliferation and pronounced modification. Little or no differences could be detected between a 4-hour and a 24-hour exposure to a high volatile ester when the amount used was 0.1 ml. or higher. At the 0.01 ml. rate no proliferation was induced with the high volatile ester when the exposure was for 4 hours, but pronounced proliferation occurred when the exposure was for 24 hours.

Table 2. Effect of amount of 2,4–D esters on the response of plants 10 days after treatment.

Amount, ml.	Response to isopropyl ester								Response to propylene glycol butyl ether ester			
	4-Hour Exposure				24-Hour Exposure				24-Hour Exposure			
	Av. height increase, cm.	Modification	Proliferation	Av. stem bending, deg.	Av. height increase, cm.	Modification	Proliferation	Av. stem bending, deg.	Av. height increase, cm.	Modification	Proliferation	Av. stem bending, deg.
0.000	11	0	0	0	9	0	0	0	10	0	0	0
0.001	11	30	0	0	8	20	10	10	10	15	0	0
0.010	10	40	0	0	5	0	25	65	11	25	0	0
0.100	5	0	35	45	2	0	40	83	10	40	10	18
1.000	3	0	25	28	2	0	40	90	7	15	30	30

Effect of temperaure. When the plants were treated over a range of temperatures (75° to 116° F.), the magnitude of the response increased with the temperature. Table 3 shows the effect of tempera-

Table 3. Effect of temperature on responses of plants 10 days after treatment with ester formulations of 2,4–D.

Ester formulation of 2,4-D	Length of exposure, hours	Amount, ml.	Responses after exposure at different temperatures, ° F.								
			75°			102°			116°		
			Av. height increase, cm.	Modification	Proliferation	Av. height increase, cm.	Modification	Proliferation	Av. height increase, cm.	Modification	Proliferation
Isopropyl	2	0.000	11	0	0	10	0	0	13	0	0
		0.001	11	20	0	10	30	0	4	0	25
		0.010	10	30	0	11	35	0	6	10	25
Propylene glycol butyl ether	4	0.000	7	0	0	6	0	0	8	0	0
		0.001	8	0	0	5	20	0	8	20	0
		0.010	8	0	0	7	30	0	9	40	0

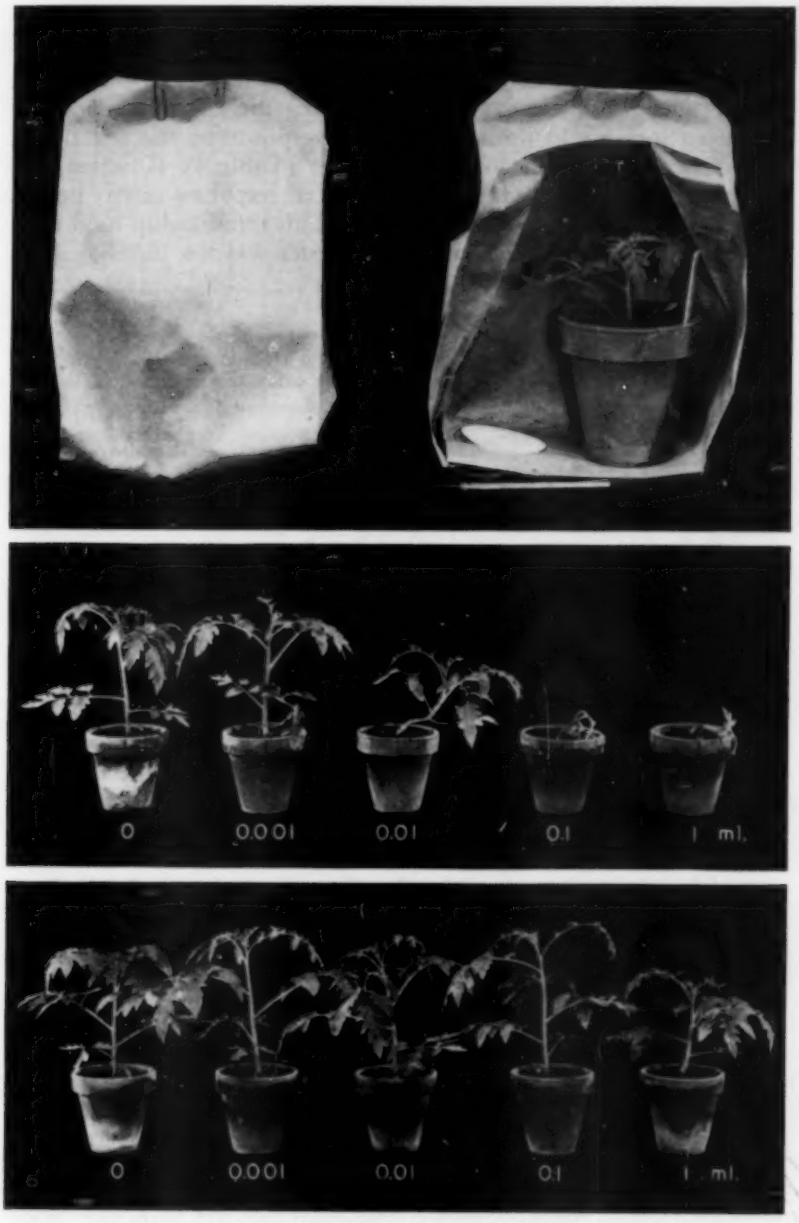

FIG. 1. (Top) Illustration of equipment and method used for exposing a tomato plant to vapors of a solution of ester deposited on filter paper by means of bacteriological inoculating loop shown in right foreground. (Middle) Responses on plants 13 days after exposure to different amounts of the isopropyl ester of 2,4–D. (Bottom) Responses 9 days after exposure to different amounts of the propylene glycol butyl ether esters of 2,4–D.

ture on the response of plants to a low and a high volatile ester. For example, 0.001 ml. of the isopropyl ester caused proliferation at 116° F. but did not at 75° F.

Effect of duration of exposure. Increasing the length of exposure caused an increase in the magnitude of response on the test plants with either a high or a low volatile ester (Table 4). However, the high volatile ester caused more pronounced responses at any period of exposure than the low volatile ester. This relationship held even though the amount of the low volatile ester was ten times as great as that of the high volatile ester.

Table 4. Effect of duration of exposure to 2,4–D esters based on the responses of tomato plants 10 days after treatment.

Length of exposure, hours	Response to 0.01 ml. isopropyl ester				Response to 0.1 ml. of propylene glycol butyl ether ester			
	Av. height increase, cm.	Modification	Proliferation	Av. stem bending, degrees	Av. height increase, cm.	Modification	Proliferation	Av. stem bending, degrees
1	13	25	0	0	12	5	0	0
2	12	35	0	0	12	20	0	0
4	9	20	5	5	9	30	0	0
6	8	20	15	13	11	35	0	0
8	9	10	10	20	12	40	0	0
16	3	0	35	50	9	25	20	10
24	4	0	40	50	7	15	30	25

Comparison of formulations. Table 5 shows the comparison of various formulations of 2,4–D and 2,4,5–T. In all cases the alkanolamine salts proved to be non-volatile from a biological standpoint. Specially prepared 2,4,5–T of high purity did not cause modification of leaves. Therefore, if the formulations of 2,4,5–T caused modification of leaves, it was assumed to be contaminated with 2,4–D. Such contamination was detected in two commercial formulations of 2,4,5–T used and listed in Table 5. None of the non-contaminated low volatile esters of 2,4,5–T formulations caused a response on test plants regardless of the amount used. This is in contrast with the low volatile esters of 2,4–D, all of which caused a response. The high volatile esters of both 2,4–D and 2,4,5–T caused pronounced responses. Therefore, these results show that the high volatile ester formulations may be distinguished from the low on the basis of the marked differences in the magnitude of responses.

Relative volatility of nine commercial formulations of 2,4–D. Table 6 shows results obtained with formulations of 2,4–D which ranged from non-volatile to high volatile substances. Of the two esters found to be of high volatility, the pentasol ester was slightly less volatile than the isopropyl. Only slight differences were noted between the six formulations found to be of low volatility.

Table 5. Response of plants to formulations of 2,4–D and 2,4,5–T. Duplicate Tests.

Formulation	Amount applied, ml.	24-Hour response		Responses after 9 to 10 days					
		Av. stem bending, degrees		Av. height increase, cm.		Modification		Proliferation	
2,4,5-T									
Alkanolamine	0.01	0	0	8	5	0	0	0	0
	0.10	0	0	8	6	0	0	0	0
Butoxyethyl	0.01	0	0	10	8	0	5	0	0
	0.10	0	0	9	7	20	20	0	0
Ethoxyethoxy propanol	0.01	0	0	7	7	0	0	0	0
	0.10	0	0	9	6	5	0	0	0
Isooctyl	0.01	0	0	9	6	0	0	0	0
	0.10	0	0	8	8	0	0	0	0
Propylene glycol butyl ether	0.01	0	0	9	7	20	20	0	0
	0.10	0	10	10	6	30	15	0	5
Isopropyl*	0.01	—	23	—	6	—	0	—	0
	0.10	—	40	—	3	—	0	—	40
2,4-D									
Alkanolamine	0.01	0	0	8	8	0	0	0	0
	0.10	0	0	9	7	0	0	0	0
Butoxyethyl	0.01	0	0	9	6	15	10	0	0
	0.10	8	0	8	7	25	20	0	0
Ethoxyethoxy propanol	0.01	0	5	9	7	30	15	0	0
	0.10	8	5	10	9	35	20	0	0
Isooctyl	0.01	8	5	9	7	25	10	0	0
	0.10	10	10	10	10	30	20	0	0
Propylene glycol butyl ether	0.01	8	15	10	9	30	25	0	0
	0.10	20	40	10	9	35	20	10	10
Isopropyl	0.01	28	40	5	5	0	5	40	20
	0.10	70	65	2	2	0	0	40	40

*Contained the equivalent of 5 lb. of acid per gallon in acetone.

DISCUSSION

Attention is called to the fact that tomato plants 2.5 to 3 inches in height were substantially more sensitive than larger plants. To obtain the same degree of response with the larger plants, higher doses of the chemicals had to be used. At a given dosage level with the smaller plants it was possible to detect relatively small differences between volatile esters. By varying the dosage levels it was possible to obtain quantitative differences in volatility based on magnitude of the responses of test plants.

After testing several types of containers and methods of application, the 20 lb. paper bag and the 7 cm. filter paper were selected as most satisfactory. To guard against contamination, the bags were used only once. No contamination occurred in any of the tests where the paper bag, filter paper technique was used. However, contamination with 2,4–D was detected in some of the formulations of 2,4,5–T. Such contamination was further proved by direct application of the solutions to leaves of the test plants.

Table 6. Initial and 9-day responses induced on tomato plants by exposure for 24 hours to different 2,4–D formulations.

2,4-D formulation, 4 lb. acid per gallon	Amount applied, ml.	24-Hour responses			9-Day responses			
		Av. stem bending, deg.	Epinasty	Total response, ranks*	Av. height increase, cm.	Modification	Proliferation	Total response, ranks*
Alkanolamine	0.01	0	0	5.5	7	0	0	2
	0.10	0	0	5.5	5	0	0	2
	1.00	0	0	5.5	6	0	0	2
Isooctyl	0.01	0	0	5.5	8	15	0	5
	0.10	10	0	12	7	25	0	9
	1.00	20	10	17	6	20	5	15
Ethoxyethoxy propanol	0.01	0	0	5.5	6	15	0	5
	0.10	10	0	12	4	25	5	17
	1.00	13	10	15.5	4	10	10	19.5
Butoxypropyl	0.01	0	0	5.5	6	20	0	7.5
	0.10	10	0	12	7	35	0	12
	1.00	13	10	15.5	5	15	5	13
Butoxyethyl	0.01	0	0	5.5	5	20	0	7.5
	0.10	25	10	18	5	20	5	15
	1.00	25	15	19	6	20	10	18
Tetrahydro-furfuryl	0.01	0	0	5.5	7	15	0	5
	0.10	0	0	5.5	8	30	0	10.5
	1.00	30	5	14	4	10	10	19.5
Propylene glycol butyl ether	0.01	0	0	5.5	6	30	0	10.5
	0.10	60	20	23	4	5	15	22
	1.00	45	20	22	4	5	25	25
Pentasol	0.01	25	20	21	8	20	5	15
	0.10	15	20	20	5	10	15	21
	1.00	40	25	24.5	5	10	20	23
Isopropyl	0.01	40	25	24.5	6	5	20	24
	0.10	70	40	27	2	0	40	26
	1.00	65	40	26	1	0	40	27

*Highest rank value represents greatest response.

SUMMARY

A simple rapid biological method for determining the relative volatility of different formulations of 2,4–D and 2,4,5–T is described. The technique consisted of enclosing in a 20 lb. paper bag a tomato plant 2.5 to 3 inches tall together with a piece of filter paper containing 0.01 to 0.1 ml. deposit of the test chemical. The period of exposure was 24 hours or less at 70° to 80° F.

Leaf epinasty and stem curvature were used as the criteria for evaluating the initial responses within 24 hours after treatment. Leaf modification, stem proliferation, and growth inhibition were used as a basis for evaluating the final responses at the end of 7 to 10 days. Leaf modification represented the minimum response, and stem proliferation and growth inhibition maximum responses. Under some conditions killing occurred, but this was preceded by pronounced proliferation and inhibition of growth. Initial responses were of value in detecting large differences between formulations, but small differences were evaluated on the basis of leaf modification 7 to 10 days after treatment.

Final responses showed that there were only slight differences in the volatility of six commercial formulations of 2,4–D esters of low volatility. Two highly volatile esters of 2,4–D differed slightly, but they were readily distinguished from those of low volatility. All ester formulations of 2,4,5–T induced less pronounced responses than the ester formulations of 2,4–D. Leaf modification was used as a criterion for determining 2,4–D contamination.

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The Effect of Sodium 2,4–Dichlorophenoxyethyl Sulfate on the Growth and Yield of Strawberries[1]

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INTRODUCTION

SODIUM 2,4–dichlorophenoxyethyl sulfate (hereafter designated as SES) has been widely tested for herbicidal use in pre- and post-emergence applications on seeded and vegetatively propagated crops. Several investigators have found this chemical to be particularly valuable for control of annual weeds in strawberries (1, 2, 3, 6, 7, 8). Their reports indicate satisfactory weed control, but for the most part contain no critical evaluation of the effect of the chemical on the strawberry plants. Field tests conducted on crops other than strawberries have indicated some crop responses which may be characteristic of the general effects to be expected from application of SES to crop plants (5, 11, 12, 13). More basic studies have shown no hormone response from application of SES to tomato foliage (9). In fact, the chemical *per se* was found to be herbicidally inactive, undergoing some change in the soil to attain its active form (10). The change from inactive to active form was found to occur in non-sterile soils over a range of pH from 3 to 7, and in sterile soils from pH 3 to 4. This change was postulated to be an acid hydrolysis of the ethyl sulfate form of the chemical to an active form, either in an acid soil or as a result of acid secretions of bacteria and fungi (14). Further research has indicated that SES is hydrolyzed to sodium 2,4–dichlorophenoxy ethanol and sodium bisulfite and that further reaction in the soil may lead to 2,4–dichlorophenoxy-acetic acid (15). The ethanol has been shown to be highly toxic to germinating seeds, but only 1/100 as toxic as 2,4–D when applied to tomato foliage (4).

The purpose of this investigation was to study some of the effects of SES on strawberry plants in field and greenhouse tests. Runner production and fruit yield as affected by SES application at different times after setting were studied in field tests. The effect of SES on root and top growth and on nitrogen, phosphorus, and potassium content was studied in the greenhouse.

EXPERIMENTAL

Effect of SES on Strawberry Yield. Yield data were taken from four field experiments begun in the spring of 1950. Runner plants produced by the plants set in 1950 bore the fruit harvested in the spring

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Credit should be given to Harry K. Bell, Horticultural Department, for co-operating in these tests. The project was supported by the Carbide and Carbon Chemical Company.

of 1951. The tests were established to study the effects on yields of rates of SES needed for weed control. Single and repeated applications were included at rates from one to six pounds per acre. The effect of the chemical on 6 common varieties was also studied. All applications were made in 100 gallons of water per acre.

The tests on the Sparkle variety at New Brunswick were conducted in plantings made in a sandy loam soil. Plots were two rows wide and 30 feet long. The experimental design of each test was a randomized block with three replications. In the first test at New Brunswick the treatments consisted of single applications of one, three and six pounds of SES per acre on June 26, repeated treatments of three and six pounds of SES per acre on June 26 and July 29, and a single application of one pound of 2,4–D per acre on June 26. Untreated check plots were included. Results of this test are presented in Table 1. Treated plots produced more fruit than the check plots, the difference being significant at the .05 level.

Table 1. The effect of SES and 2,4–D on yield of strawberries, New Brunswick, N. J., 1951.

Treatment	Yield in grams per plot[1]
1. Check—hand hoed	5,224
2. 1 pound of SES June 26	5,228
3. 6 pounds of SES June 26	8,962
4. 3 pounds of SES June 26	6,683
5. 3 pounds of SES June 26 and July 29	7,897
6. 6 pounds of SES June 26 and July 29	5,917
7. 1 pound of 2,4-D applied June 26	6,409

[1]Average of three replications.

The second test on the Sparkle variety at New Brunswick consisted of a single application of one, three and six pounds of SES per acre, one pound of 2,4–D per acre, and untreated check. All applications were made on July 27. Table 2 shows the yield data from this test in which there were no significant differences in yield due to treatments. However, the analysis of variance of this test suggested that the 2,4–D treatment may have reduced yield. There was no such suggestion in a similar comparison made in the first test on the Sparkle variety at New Brunswick.

Table 2. The effect of SES and 2,4–D on yield of strawberries, New Brunswick, N. J., 1951.

Treatment	Yield in grams per plot[1]
1. 1 pound of SES July 27	13,299
2. 3 pounds of SES July 27	16,617
3. 6 pounds of SES July 27	14,625
4. 1 pound of 2,4-D July 27	12,685
5. Check—hand-hoed	16,780

[1]Average of three replications.

A test was made at Matawan, New Jersey in a commercial field of the Sparkle variety set in a sandy loam soil. Plots were 2 rows wide and 30 feet long. The experimental design was a randomized block with three replications. Treatments were applications of three and four pounds of SES per acre and untreated checks. The first applications were made on June 20 and the plots were retreated on August 10. Data obtained from this test are shown in Table 3. Differences in yield were not statistically significant.

Table 3. The effect of SES on the yield of strawberries, Matawan, N. J., 1951.

Treatment	Yield in grams per plot[1]
1. 4 pounds of SES per acre June 20 and August 10	21,172
2. 3 pounds of SES per acre June 20 and August 10	20,410
3. Check—given normal field cultivation and hoeing	20,256

[1]Average of three replications.

In the yield test on six strawberry varieties at New Brunswick, Dorsett, Pathfinder, Redwing, Redcrop, Fairfax and Midland varieties were treated with three pounds of SES per acre on June 26 and July 28. Untreated check plots were included in the test. Plots were two rows wide and 15 feet long, with three replications. The comparison of treated with untreated plots in this test indicated that yield of treated plots exceeded that of untreated plots, and the yield of the individual varieties was not significantly decreased by treatment. The results of this test are shown in Table 4.

Table 4. The effect of SES on yields of six varieties of strawberries, New Brunswick, 1951.

Variety	Yield in grams per plot[1]	
	Check	6 pounds of SES per acre
Dorsett	11,971	12,087
Pathfinder	10,943	12,953
Redwing	7,746	5,833
Redcrop	4,808	7,583
Fairfax	4,748	5,671
Midland	3,013	3,778
Treatment average	7,178	7,954

[1]Average of three replications.

The increase in yield of treated over check plots in two of the tests, and a tendency for yield to increase with increasing rate of application of SES in two tests may have been due to reduced weed competition in treated plots during 1950. Check plots were hand-hoed after weed counts were taken, but competition from weeds which were allowed to grow until counted might account for the reduction in check plot yields. This possibility is substantiated by the fact that plots treated with one pound of SES per acre, which did not control weeds effectively, yielded no more than check plots in the first test on Sparkle at New Brunswick.

Effect of SES on Growth of Strawberry Plants in the Greenhouse. A greenhouse study was conducted to measure root and top development of strawberry plants treated with SES. It was felt that field observations might not detect these responses, and that as the chemical might presumably be used soon after planting in the spring, or when runner plants are rooting, information on the effects of the chemical on root development would be extremely important.

In February, 1951, about 100 Sparkle plants were dug from the nursery. Sixty similar plants were selected from this group and divided into fifteen groups of four plants. Root length measurements, leaf counts and green plant weights were recorded for each plant. Each plant in three of the groups was divided into roots and tops, oven-dried, and per cent dry weight calculated.

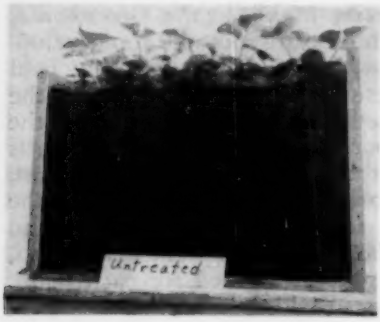
Each remaining group of four plants was planted in a modified 15 x 22½ inch flat set on edge. One side of the flat was formed by a pane of glass through which root development was observed periodically. Ten days after planting, four flats selected at random were sprayed with an aqueous solution equivalent to three pounds of SES per acre. Four others selected at random were sprayed with the equivalent of six pounds of SES per acre. Four flats were retained untreated as checks. The entire plant surface as well as the soil surface of the flat was covered by the spray.

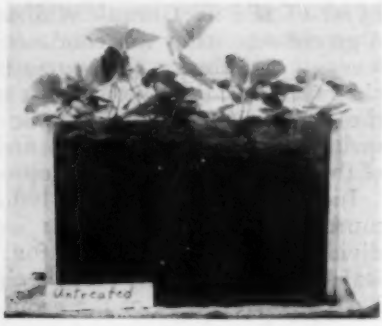
The flats were placed on a greenhouse bench where they were kept for three months after treatment. During this period the plants were supplied with adequate water, and flower buds and runners were removed to promote root growth.

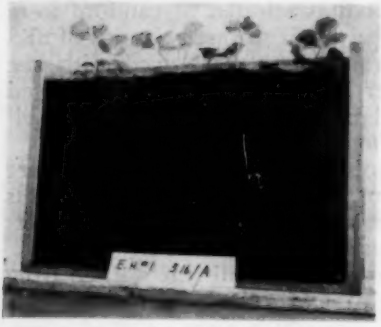
On May 15 the plants were harvested. The soil was washed from the flats, and the plant roots washed free of soil. Each group of four plants was separated into roots and tops which were weighed green, oven-dried, and weighed dry. Growth was measured in grams increase in dry weight per gram original dry weight; original dry weight was calculated from the dry weights of plants in the three groups selected for the purpose at the start of the test. The increase in dry weight of plants is shown in Table 5. Untreated plants made more total growth than treated plants. Both roots and tops were inhibited by SES but roots were inhibited to a greater extent. Examination of Figures 1 and 2 indicates that roots were inhibited considerably during the first month but at the end of three months root growth in treated flats was comparable to that in untreated flats. The apparent dis-

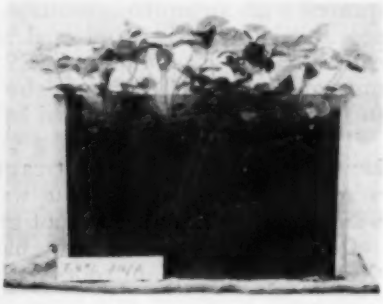
Table 5. Effect of SES on root and top growth of strawberry plants grown in the greenhouse.

Treatment	Grams increase in dry weight per gram original dry weight		Per cent of check	
	Tops	Roots	Tops	Roots
1. Check	7.52	3.82	—	—
2. 3 pounds of SES per acre	6.28	3.03	83.2	79.3
3. 6 pounds of SES per acre	6.30	2.57	83.8	67.3
Plant parts L.S.D. .05 .47				
.01 .82				









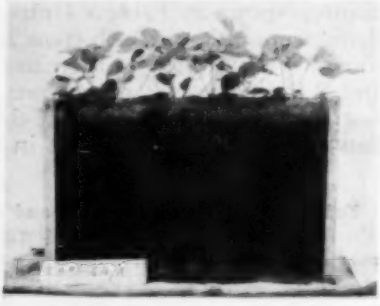


FIG. 1. Effect of SES on root growth of strawberry plants one month after treatment. Note decreased growth with both rates of SES.

FIG. 2. Effect of SES on root growth of strawberry plants three months after treatment. Note the extensive root growth in treated flats indicating that the inhibition evident one month after treatment has been outgrown.

crepancy between dry weight yields and growth as shown in figure 2 is due in part to lower dry weights in treated than in untreated plants. Dry weight of roots in treated plants when harvested was approximately 90 per cent and 80 per cent of check plants for 3 and 6 pounds respectively. Roots on treated plants developed later as a result of inhibition from SES; consequently they were younger when harvested.

Effects of SES Applied at Different Times After Setting in the Field. As the greenhouse study showed that the growth of strawberry plants was inhibited in the period immediately following the application of SES, a field test was established to study the effects of time of application of SES on runner initiation and rooting. Sparkle strawberry plants were planted April 8 in a Sassafras loam soil. Plots were two rows wide by fifteen feet long, with provision for three replications in a randomized block design. Treatments consisted of a single application of 2.7 pounds of SES per acre in ten gallons of water. The first treatment was made April 9, the second ten days later, and subsequent treatments at intervals of two weeks. The entire area was hand-hoed for uniform weed control.

Rooted runner plants were counted in each plot on August 1 and November 1. Results of these counts are shown in Table 6. Plots treated June 8 and June 25 had less rooted runners than the other plots on August 1. SES applied on these dates would have been present in the soil during the period of first runner rooting. On November 1 these plots contained as many rooted runners as the other plots. The April 9 treatment was the only one which resulted in fewer runner plants November 1 due probably to injury to parent plants from the application one day after planting.

Yield data obtained in the spring of 1952 are shown in Table 6. The data indicate that treatment at the time of planting reduced yield, and treatment four weeks after planting increased yield. The increase in yield of the plots treated four weeks after planting seems to be associated with a high number of rooted runners on August 1 in these plots, but other treatments showing an equally high number of rooted runners on August 1 do not exhibit increased yields. It is

Table 6. Effect of date of application of 2.7 pounds of SES per acre on the number of rooted runner plants in 1951 and yields in 1952, New Brunswick, New Jersey.

Date of treatment[1]	Rooted Runner Plants		Yield in grams
	August 1	November 1	
Check	569	1200	28,281
April 9	603	1117	23,690
April 23	577	1515	28,172
May 9	865	1515	39,977
May 26	750	1462	30,068
June 8	408	1552	30,528
June 25	487	1342	29,506
July 12	637	1342	30,573
August 2	632	1642	33,768
L.S.D. .05	296		

[1]April 9 treatment made one day after planting.

most interesting to note the remarkable similarity in total yields among the various treatments regardless of number of runners rooted on August 1, excepting the treatments applied one day and four weeks after planting. It appears that no treatment except the first reduced strawberry production on a total weight basis, disregarding berry size and omitting normal mechanical cultivation which, as a result of its pruning action, might have emphasized the importance of the first-formed runners in the productive capacity of the various plots. It might be concluded that application of SES any time later than two weeks after planting did not reduce yield in this test.

If SES has an effect similar to that of 2,4–D on the chemical composition of plants, the total increase in number of runners in treated plots might be explained by a condition of vegetative growth associated with a reduction in starches and insoluble sugars and an increase in soluble sugars. Table 7 shows the results of a partial chemical analysis of the dried plant material from the greenhouse test. There appears to be a tendency for phosphorus and potassium content of both tops and roots to increase with increasing rates of SES. This increase is of the same character as the change in chemical composition of plants in response to application of 2,4–D.

Table 7. Partial chemical analysis of strawberry plants treated with SES[1].

Treatment	Tops			Roots		
	N	P	K	N	P	K
Untreated	1.9	.26	1.73	1.0	.19	.77
3 pounds of SES per acre	1.9	.24	1.88	1.1	.19	.74
6 pounds of SES per acre	2.1	.29	1.93	1.1	.23	1.07

[1]Expressed as per cent dry weight of plants. All figures represent means of four samples of four plants each, except untreated roots (mean of two samples), tops treated with three pounds of SES per acre (mean of three samples), and roots treated with three pounds SES per acre (mean of two samples).

DISCUSSION

Strawberry yields were not reduced by rates of SES necessary to control weeds providing the chemical was not in the soil during early rooting of parent or runner plants. As much as 12 pounds of SES per acre in the setting season did not reduce yields the following year which clearly indicates the tolerance of strawberries from the standpoint of yield. Careful studies of the effect of SES on root development, however, indicated that SES is inhibitory to root growth. Initial inhibition of roots from SES applied immediately after setting in the greenhouse was largely outgrown by three months after treatment. In the field the number of early runner plants was reduced with SES applied either immediately after setting or during the period when these early runner plants were rooting. However, application during the period of early runner production did not reduce the total number of runner plants established on November 1 indicating that the effect of SES was that of delaying runner establishment. A reduction in the number of early runner plants is serious

nevertheless, since it is recognized that maximum yields are frequently directly related to the number of early runner plants the previous year. Delay in runner rooting could be avoided by timing application of SES so that the chemical is not present in the soil during the rooting of early runners. In the tests reported here soil which had not been treated for five weeks was suitable for normal rooting while treatments three weeks prior to rooting had an inhibitory effect on rooting. It is recognized that persistence of SES will vary with soil and climatic conditions. In tests not reported here relatively high temperatures (75–85° F) resulted in rapid disappearance of herbicidal activity from soil while inhibitory effects persisted approximately two months in soil stored at 35° F.

SUMMARY

1. Yields of seven strawberry varieties were not reduced by applications of sodium 2,4–dichlorophenoxyethyl sulfate in excess of amounts necessary to provide pre-emergence control of weeds. Strawberry yields tended to be reduced by application of one pound of 2,4–D per acre.

2. Growth measurements of plants grown in the greenhouse showed that sodium 2,4–dichlorophenoxyethyl sulfate applied immediately after setting inhibited root and top growth of strawberry plants temporarily. Inhibition of roots in particular was marked at one month after treatment. Three months after treatment there was little apparent difference between treated and untreated plants.

3. The number of established early runner plants in the field was reduced by the presence of sodium 2,4–dichlorophenoxyethyl sulfate in the soil during the period of early runner formation. At the end of the growing season treated plots contained as many rooted runners as untreated plots.

4. Applications of sodium 2,4–dichlorophenoxyethyl sulfate for weed control in strawberries should be so timed that the chemical is not in the soil during early rooting of parent plants and maximum production of early runner plants.

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Persistence of Sodium Trichloroacetate in Different Soil Types[1]

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Introduction

Recently sodium trichloroacetate (TCA) has come to the front as a useful herbicide for the control of annual or perennial grasses. The object of this paper is to report the persistence of the chemical in different types of soils as related to time and rates of applications.

Review of Literature

McCall and Zahnley called attention to the grass killing properties of trichloroacetates in 1949 (17). Sodium trichloroacetate, abbreviated as TCA in this paper, has given satisfactory results for the control of grass weeds (4, 5, 8). It has also caused a severe stunting in Russian thistle *(Salsola kali)* and red root pigweed *(Amaranthus retroflexus)* (8) and has inhibited the growth of many other plants (10).

It has been found that the soil, atmospheric conditions, variety or species of the weed plants, and their stages of growth influence the rate of the herbicidal action of TCA (1, 2).

The soil applications of TCA on quack grass at various rates, 10, 20, 30, 40, 50, 60, 75, 80, 100, 120, 125 and 150 pounds per acre, showed that the percentage kill was proportional to the rate of application of TCA (11, 13, 14, 15, 16). Rates over 100 pounds gave satisfactory results in suppressing the top growth of the grass and no resprouting was observed at any application of 150 pounds per acre (4, 7, 14).

Soil sterility caused by application of TCA appeared to be temporary. The toxic conditions of the soil lasted only 60 to 90 days (17). Subsequent planting of oats, alfalfa (12) and corn (22) on the treated plots did not show any injurious effects.

Experiments (23) showed that soil moisture had a greater significance, within the range of applications used, than did the actual rate or date of application. In another series of the experiments high moisture content of the soil led to inferior results (3, 6). The best results were obtained on a moderately dry soil with scant to moderate rainfall during a one month period following the spray (3). Watson (21) found a direct correlation between rainfall following spray and degree of quack grass control.

Materials and Methods

In order to determine the residual effects of TCA in relation to crop growth on different types of soils, an experiment in split plot design was arranged.

[1]Journal Article 1507 from the Michigan Agricultural Experiment Station.

Equal volumes of soils – Oshtemo sand, Brookston clay loam and muck weighing 4,000 grams, 3,700 and 1,700 grams respectively, were mixed with amounts of TCA corresponding to the rates of 15, 30 and 60 pounds per acre and placed in number 10 cans. The calculations were based on the surface area of the cans and rates are expressed on the acid equivalent basis. The TCA was added to and mixed with the various soils 21, 42, 64 and 108 days prior to sowing the crop. Distilled water was added immediately following treatment.

Seven-hundred ml. of distilled water were added to each can of clay loam and muck soils while cans containing Oshtemo sand received 500 ml. only.

During the entire period of the experiment the cans were weighed frequently. Sufficient water was added to each pot to bring the moisture content back to its original level. The losses of water were due to the surface evaporation and transpiration by wheat plants. There was no loss because of leaking as the cans were water-tight.

Wheat was used as a test plant as it is known to have sensitivity to TCA at rates as low as 5 pounds per acre (2). The cultures were seeded to Henry spring wheat on July 9, 1950; 20 seeds were placed in each can at a depth of ½ to 1 inch.

Plant growth was considered to be a direct measure of toxicity of the compounds (19). With this in mind the data were recorded for rate of growth, fresh weight of the tops, dry weight of the tops and dry weight of the roots. The rate of growth is shown by Figures 1, 2, and 3.

The main crop was harvested on August 23, 1950. The plants growing in soils which received the largest applications of TCA just 21 days before the sowing of the crop were harvested earlier as they would have been dead by August 23.

EXPERIMENTAL RESULTS

It was clear from the recorded observations that the amount of growth, expressed as fresh weight of tops, dry weight of tops and dry weight of roots, was directly related to the amounts of TCA applied. For instance, the fresh top-growth, where wheat was planted on muck soil 21 days after TCA was applied at the rate of 60 pounds per acre, amounted to 0.46 grams per pot as compared to 1.50 grams per pot where the rate was 15 pounds per acre and 14.00 grams per pot where the chemical was not applied. Similar results were obtained where TCA was applied on clay loam and sandy soils where the elapsed time between treatment and planting was 21 days.

The residual effect of TCA was less in the sandy soil than it was on the muck and clay loam. This is shown by the results obtained when the elapsed time between treating with TCA and planting of wheat was 42 days. In the case of sand, where 15 pounds per acre of the chemical was applied, the wheat was not appreciably injured and only slight injury resulted where the applications were 30 pounds per acre. At 60 pounds per acre application wheat yields were reduced from an average of 19.33 grams to 10.66 grams per pot. In contrast to the results obtained in sandy soil all applications of TCA

on clay loam and muck soils caused pronounced injury to wheat plants where the elapsed time between application of TCA and planting of wheat was 42 days.

Where the elapsed time between treatment and planting was 64 days the results show that wheat grown on the sandy and clay loam soils was not injured when the applications of TCA were as high as 60 pounds per acre. On the other hand the residual effect was quite pronounced on the muck soil even 108 days after application of the chemical.

The growth-rate curves shown in Figures 1, 2, and 3 show graphically the variations which existed in the results obtained from different soils. It may be seen from Figure 1 that on muck soil 15 pounds of TCA per acre significantly affected growth where the elapsed time was 21 or 42 days but had little effect where more than 42 days elapsed. Where the rate of application was higher, 30 or 60 pounds per acre, growth was affected even when 108 days had elapsed.

It can be seen from the curves representing the plant growth rate for clay loam soil, Figure 2, that the growth of wheat was not depressed in the pots where planting had occurred 64 or 108 days after the application of 15, 30 or 60 pounds TCA per acre. The growth curves for these time periods are almost identical with those for the controls, thus indicating quite clearly that the toxic or residual effect disappeared after 64 days from the time of application. The depression of growth was pronounced only where planting was done 21 or 42 days after the chemical was applied.

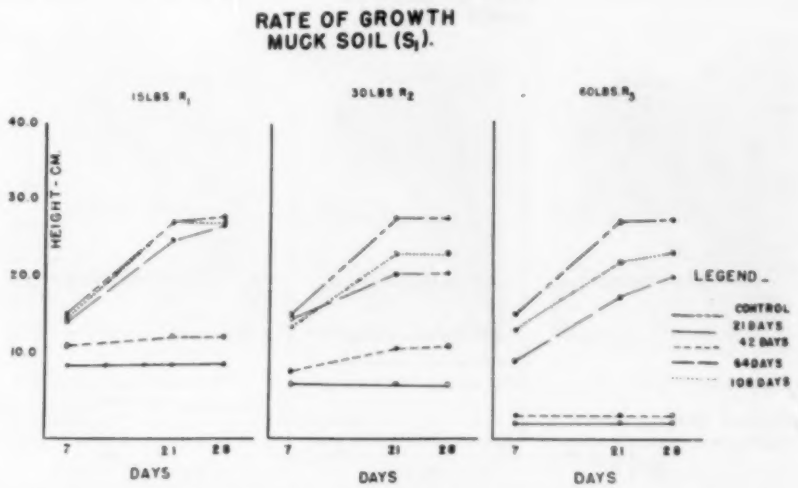

FIG. 1. The effect of rate and date of application of TCA on the rate of growth of wheat on muck soil. The chemical was applied 21, 42, 64 and 108 days prior to planting date of wheat seeds.

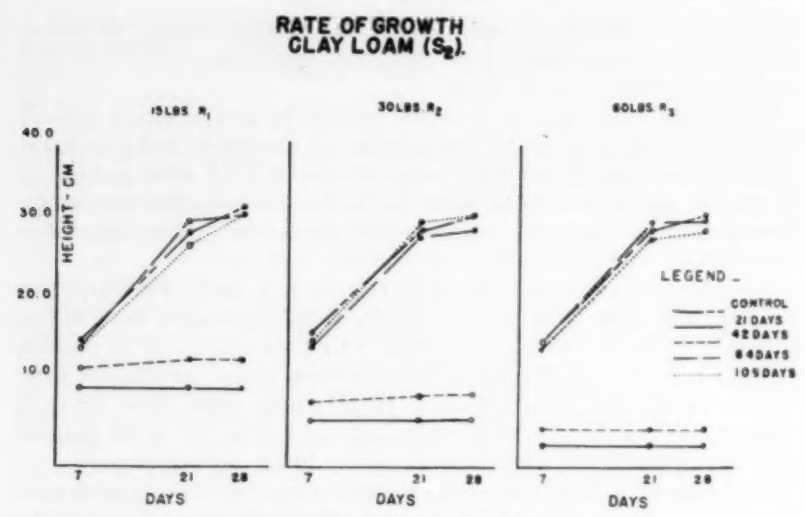

FIG. 2. The effect of rate and date of application of TCA on the rate of growth of wheat on clay loam soil. The chemical was applied 21, 42, 64 and 108 days prior to plant date of wheat seeds.

The effect of TCA application on sandy soil can be seen in Figure 3. This shows that the 15 pound rate depressed growth only when the application was made 21 days prior to planting. The two heavier rates depressed growth where elapsed time was either 21 days or 42 days.

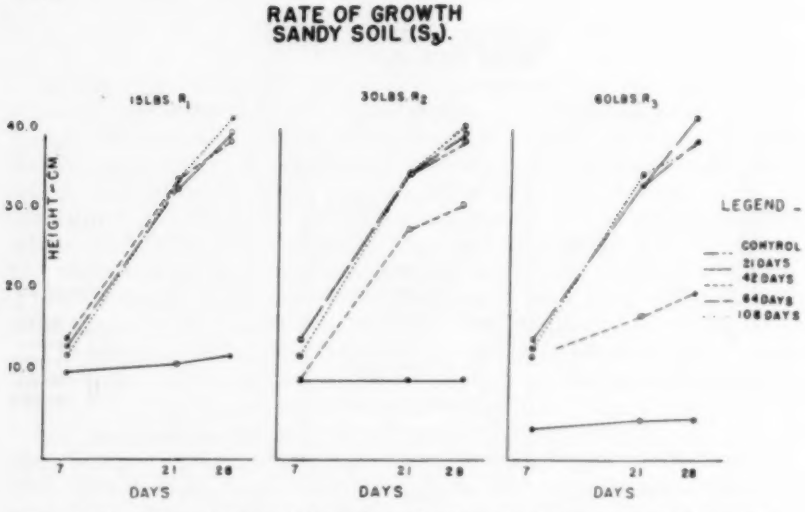

FIG. 3. The effect of rate and date of application of TCA on the rate of growth of wheat on sandy soil. The chemical was applied 21, 42, 64 and 108 days prior to planting date of wheat seeds.

Figure 4 depicts the effect which TCA applications to the three soils had on the growth of wheat plants. Also evident in the picture is a contrast between the plants grown in untreated muck and plants grown in muck treated with TCA where the elapsed time, after application, was 108 days. A similar growth trend for the plants grown on clay loam soil (S_2) can be seen where the elapsed period after application was 21 or 42 days in contrast to two longer periods of 64 and 108 days. It may also be observed that plants grown in sandy soil show a marked contrast between control plants and treated plants where the elapsed time, after application, was only 21 days.

The analysis of variance showed that significant differences occurred between times (elapsed time from the date of application to the date of planting), rates of applications, and soils. It is interesting that second and third interactions are also significant. For instance, consider times and soils. The injurious effects of TCA disappeared sooner in the sandy soil than in either of the other two soils and lasted longer in the muck. Some injurious effect persisted in the muck even to 108 days.

One would expect the interaction between rates and times to be significant. Such was the case, particularly on the two mineral soils.

The significance of the soils and rates interaction at the 21-day interval is explained by the fact that rates made more difference in the sandy soil than in the other two soils. The three treatment rates produced results in clay loam and muck which were similar and of greater magnitude than those obtained in the sandy soil. On the other hand, when final time is considered, the opposite is true. Sixty pounds of the chemical still caused a pronounced injury in the muck soil but 15 pounds per acre was not injurious. With the other soils, at that time interval, none of the applications was injurious.

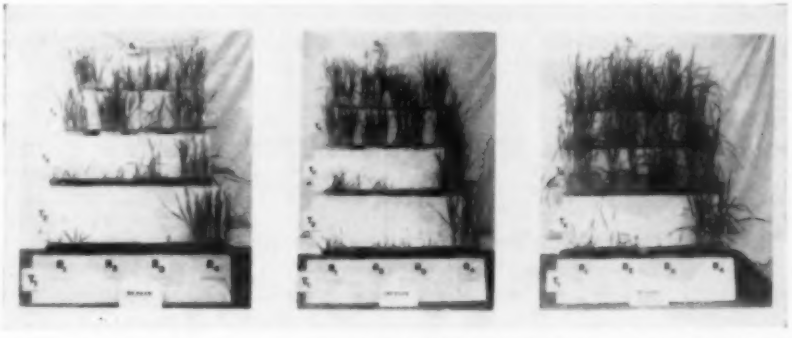

FIG. 4. The effect of TCA on growth of wheat plants 30 days after planting.

S – soils	R – rates	T – time elapsed between treatments and planting date.
S_1 muck	R_1 15 lbs. TCA P.A.	T_1 21 days.
S_2 clay loam	R_2 30 lbs. TCA P.A.	T_2 42 days.
S_3 Oshtemo sand	R_3 60 lbs. TCA P.A.	T_3 64 days.
	R_4 Control	T_4 108 days.

By referring to Table 1 it is possible to see the effects of rates, times, and soils. In each case the other variables are averaged. For all times of application and all soils, significant differences in the fresh weight of the tops but not in the dry weight of tops resulted from all treatment rates.

A consideration of time, including all rates and soils, show that significant differences resulted in all three yield categories. Likewise, the same was true of the differences caused by soils when all time and rates were thrown together.

DISCUSSION OF RESULTS

The results presented in the preceding pages show that under certain conditions TCA may affect the growth of wheat plants. To explain the reason for injury, wheat seeds were planted in Oshtemo sand immediately after the application of 30 pounds of TCA per acre. It was not until 10 days after planting that plants began to show symptoms of injury. Apparently 30 pounds of TCA per acre when mixed with soil is not sufficient to affect the germination of wheat seeds. It is not until the plants have developed a root system that they take in sufficient chemical to cause injury. As the roots become more widespread the injury becomes more pronounced.

Symptoms of injury appeared first on plants grown in soil which received treatments 21 days before the sowing of the seeds. The severity of injury was related to the amounts of TCA applied. These findings confirm the results obtained by other workers (13, 14, 15, 16). The nature of soil had very little effect on the amount of injury

Table 1. A summary of the yield data for all treatments, rates, times and soils.

	Rates—including all times and soils				L.S.D.**	
	R_1	R_2	R_3	R_4	5%	1%
Fresh weight of tops*....	12.68	11.98	10.38	18.33	0.977	1.297
Dry weight of tops.....	0.37	0.36	0.30	0.55	0.299	0.397
Dry weight of roots.....	1.23	1.23	0.99	1.72	0.140	0.186
	Times—including all rates and soils					
	T_1	T_2	T_3	T_4	5%	1%
Fresh weight of tops.....	5.50	9.43	19.72	18.72	1.280	1.384
Dry weight of tops.....	1.79	2.80	5.81	5.40	0.996	1.509
Dry weight of roots.....	0.64	1.05	1.79	1.68	0.203	0.307
	Soils—including all times and rates					
	S_1	S_2	S_3			
Fresh weight of tops.....	7.76	14.62	17.65	——	1.664	2.292
Dry weight of tops.....	2.04	3.90	4.05	——	0.403	0.555
Dry weight of roots.....	0.76	1.05	2.07	——	0.276	0.380

*All data expressed in grams per pot. **Least significant difference.

Legend:—

S—Soils
S_1—muck
S_2—clay loam
S_3—Oshtemo sand

R—rates
R_1—15 lbs. TCA P.A.
R_2—30 lbs. TCA P.A.
R_3—60 lbs. TCA P.A.
R_4—Control

T—time elapsed between treatments and planting time.
T_1—21 days
T_2—42 days
T_3—64 days
T_4—108 days.

which occurred during this time interval. The 42 day interval almost was sufficient to eliminate injury in cans containing clay and Oshtemo sand. This was especially true of Oshtemo sand where plant growth on treated pots was comparable to those of untreated pots.

Plants growing in treated muck were affected adversely even at low rates of TCA applications and for long intervals of time. The suppression of plant growth was directly related to the amount applied.

Apparently, from the observations, yield data and growth curves presented, the toxicity of TCA in soil depends upon the soil structure, moisture-holding capacity and organic content of the soils.

The particles of Oshtemo sand are of comparatively large size and hence expose little surface as compared to an equal volume of muck or Brookston clay loam particles. Sand particles do not take part, to any great extent, in the physical and chemical activities of the soil. Relatively large spaces between the particles facilitate the movements of air and drainage water. TCA, which is readily soluble in water (9), may have been leached from the upper layers of the sandy soil by gravitational movements of the water. The cultures were held at field capacity during the various time intervals. With longer time intervals, of course, more water was applied, hence there was more opportunity for leaching.

The moisture-holding capacity of the soil partly may explain the crop growth differences in three soil types used in the studies. Experiments conducted by Robbins *et al* (19) with sodium chlorate showed that its movement is much faster in sandy soil than in heavier soils.

In the muck and clay loam soils the long persistence of the herbicide may be explained on the basis of colloidal clay and organic matter content, the main constituents of such soils, and the fineness of the soil particles. The movement of the compound in such soils is restricted by the colloidal adsorption of the chemical. Since the colloidal soil particles are charged bodies, they may hold water molecules and dissolved herbicide molecules readily and firmly. The soil exhibits retention against leaching due to positive and negative charges which are carried by colloidal nuclei and water molecules respectively.

SUMMARY

The sodium salt of trichloroacetic acid was applied at three rates (15, 30 and 60 pounds per acre) to pots containing muck, clay loam, and sandy soils. Treatments were made 21, 42, 64 and 108 days before wheat seeds were planted.

The results may be summarized as follows:

1. TCA proved very effective in suppressing the growth of wheat plants. This was borne out by fresh and dry weight of tops, dry weight of roots, and periodic rate of growth of plants.
2. The extent of injury was related to the rate of application of the compound, the 60-pound applications being the most injurious of all.
3. The greatest suppression of growth resulted, irrespective of

the nature of the soil, when TCA was applied 21 days before the sowing date of wheat seeds.

4. In the second period, where application was made 42 days before the sowing time, there was little evidence of TCA injury to plants growing in sandy soil while those growing in muck were badly injured. The injury to plants grown on clay loam was intermediate.

5. In clay loam and sandy soils the dissipation of TCA, as shown by wheat yields, was well under way by the time 42 days had elapsed and was complete by the end of 64 days. However, this did not hold true with muck soil where injury occurred even after 108 days.

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"The Responses of Tomato Plants to Vapors of 2,4–D and/or 2,4,5–T Formulations at Normal and Higher Temperatures"

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Introduction

The current widespread use of ester and amine formulations of 2,4–dichlorophenoxyacetic acid (2,4–D) and/or 2,4,5–trichlorophenoxyacetic acid (2,4,5–T) has made apparent the potential vapor hazard of these herbicides in their injury to susceptible crop plants growing nearby. A method used for evaluating the volatility of proprietary formulations was reported previously (1,2) using temperatures of 70° to 75° F. At this "normal" temperature eighty commercial ester preparations representing thirty-one different formulations of 2,4–D and/or 2,4,5–T showed, conclusively, that esters such as the isopropyl, butyl, ethyl, amyl, and pentyl individually or in mixture were volatile; and the iso-octyl, butoxyethanol, tetrahydrofurfuryl, polypropylene glycol, and propylene glycol butyl ether esters were low volatile. These formulations do not comprise all the commercial preparations tested but are given only to indicate the extent of volatility found for 2,4–D and 2,4,5–T ester herbicides commonly available on the market.

Vapor studies with amines at 70° to 75° F. showed that none of the formulations tested produced epinastic or formative responses in tomato plants. Accordingly, higher temperatures were maintained by slight modification of the method as previously reported although the principal of test, i.e., the use of a calibrated forced air stream passed over the ester or amine formulation was retained.

It has been brought to our attention that vapors from amine or low volatile ester formulations were causing injury to susceptible crop plants, as grape and cotton, in some areas of the west where the products were commercially used under extremely high temperature conditions.

This paper reports the formative effects on Rutgers tomato plants of vapors measured for proprietary esters of 2,4–D and/or 2,4,5–T effused at 70° to 75° F, and the change in response obtained with some ester formulations found to be low volatile at 70° to 75° F. when temperature was raised to 90° F. and to 120° F. The reaction of test plants to amine formulations of 2,4–D at these higher temperatures was compared with that of esters used as controls.

Experimental Procedure

Higher temperatures were achieved by using a thermoregulated, electrically heated, circulating water bath in which was submerged the air line and bottom halves of the test tubes containing the prod-

[1]Pathologist and Pathologist, in charge, respectively, Fungicide & Herbicide Unit, Pest Regulation Section, Plant Control Branch, Agricultural Research Service, U. S. Department of Agriculture.

FIG. 1. Arrangement of tubes containing product to be tested in the heated water bath and the test tomato plants outside the bath. Bag removed from 1 of the 8 units in the system to show the delivery tube and its position relative to the plant. Note coils of rubber tubing beneath the water surface through which the forced air courses before passing over the product under test.

ucts to be tested (see Fig. 1). In addition to the checks and controls introduced for every test, 5 products could be tested simultaneously. With the water bath heated to 94° F. the forced air temperature was found to be 86° to 88° F., and with the bath temperature raised to 122° F. the forced air temperature was maintained at 107° to 110° F. The former is referred to as 90° F., and the latter as 120° F. A thermometer maintained in one of the units (test tube containing product with glass tubing for air inlet and outlet, see Fig. 2) afforded constant observation of the forced air temperature during these tests. To reduce the possibility of condensation of the warm effusate on to relatively cool glass tubing, the room air temperature was regulated to 80° to 85° F. No condensation was observed to occur with these temperatures. Test plants were placed under ¼ barrel size paper bags outside the water bath, and the effusate was directed into the bag through a glass arm. Unbagged plants were continuously maintained in the room as indicators of contamination by formative concentrations of ester or amine vapors.

Tomato plants placed in an air temperature of 120° F. in a Freas electric oven for 16 hours showed slight wilting at the end of this interval. It was apparent that the test tomato plants should not be subjected for any sustained period of time to this higher temperature because of the wilting effect which may alter the action of the vapors of 2,4–D and/or 2,4,5–T on the plant and also confuse the reading of the true action of the chemical in terms of plant responses.

The sodium salt of 2,4–D with no apparent volatility when used as a check, and a butyl and a butoxyethanol ester of 2,4–D used as controls, the intervals of exposure of plants to vapors, the procedure

FIG. 2. A close-up of unbagged unit of the system showing arrangement of air tube, vapor delivery tube, thermometer for measure of the forced air temperature, position of the test plant, and manner of bagging the plants.

for evaluating response, and all the precautions taken to avoid contamination of one product with another, were the same as in the method already published (1, 2). This method and the modifications instituted for higher temperature studies are believed to afford a comprehensive measure of probable biological effects of vapors of esters and amines of 2,4–D and/or 2,4,5–T.

EVALUATION OF RESPONSE

A single value to describe the volatility hazard of any one commercial product cannot be determined because response varies both with duration of exposure. Perusal of the data obtained from 80 commercial ester formulations indicated that response of tomato plants to any given type of ester was essentially the same even when amounts of the active acid present varied widely. Minor variations did occur which might be ascribed to such factors as the surface active agent (3), carrier, or mixture of the esters with herbicides other than 2,4–D or 2,4,5–T. (The latter are not included in this report).

Even these slight variations did not appear to influence the magnitude of response. It is therefore proposed that for its utilitarian value esters of any one type be grouped and considered as a unit. Averages of the responses for 2,4, and 16-hour exposure intervals, determined upon removal and 24, 48, and 72 hours following, should be taken to represent the probable effects on tomato plants of the vapor effused from each of the several types of esters reported.

Although the response 72 hours following exposure is critical for the evaluation of volatility, the earlier observations are also presented to indicate the manner in which responses may be intensified or mitigated in time. The value of 2.5 for response used to separate low volatile and volatile formulations is considered feasible on the basis of experience with this large number of bio-assays.

EXPERIMENTAL RESULTS

Response of Rutgers tomato plants to butyl esters of 2,4–D at normal temperatures (70° to 75° F.):

The same magnitude of response appears to have been evidenced in Rutgers tomato plants regardless of the per cent acid present. In

Table 1 is summarized the formative reactions obtained by exposure to 4 of the 11 butyl esters tested. These represent the distribution for the active acid of the commercial products that were bioassayed. It is apparent that the butyl ester containing 11.5% acid caused similar formative responses in test plants 72 hours following exposure for 16 hours as did formulations with greater acid content. It is likewise apparent that the response following shorter periods of exposure was not as severe as that of the other 3 butyl formulations at the time of final evaluation (72 hours). Thus, the amount of acid present appears to influence the reaction to vapor following short exposure periods, but this effect is masked with longer exposures. Comparison of the average response of these 4 butyl 2,4–D ester formulations with the average computed for the 11 products tested also shows essentially the same response thereby suggesting no change in biological significance for probable responses to vapors of butyl 2,4–D ester formulations containing from 11.5% to 39.6% acid.

It would appear reasonable to interpret this parallelism in response with wide variation in active acid on the basis of critical or threshold concentration. In accordance with the scale of response used in these tests (see footnote [1], Table 1) a threshold concentration would be one which causes an average response computed as a reaction class of 2.5. Thus, the comparative low value of 11.5% acid is probably above a threshold concentration and hence no real differences are manifested in response to these formulations with active acid content as high as 39.6%. For formulations containing less than 11.5% acid, rate and degree of response might vary more widely than indicated by the several commercial products tested.

Table 1. Evaluation of response of Rutgers tomatoes at 4 intervals following exposure for 2, 4, and 16 hours at 70° to 75° F. to vapors of several Butyl esters of 2,4–D and other esters or salts of 2,4–D.

Commercial formulation	Pct. acid	Average formative effect[1] at 4 intervals after exposure											
		Upon removal			24 hours			48 hours			72 hours		
		2	4	16	2	4	16	2	4	16	2	4	16
Butyl 2,4-D	11.5	2.0	4.3	6.0	3.7	5.3	6.0	4.0	5.3	6.0	4.3	4.7	6.0
do	30.5	2.3	5.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	5.3	6.0
do	32.4	2.3	3.3	6.0	6.0	6.0	6.0	5.7	6.0	6.0	5.3	5.7	6.0
do	39.6	2.7	4.7	6.0	6.0	6.0	6.0	5.3	6.0	6.0	5.3	5.7	6.0
(Average—4)	—	2.3	4.3	6.0	5.4	5.8	6.0	5.3	5.8	6.0	5.3	5.4	6.0
(Average—11)	—	2.7	4.2	5.9	5.4	5.8	6.0	5.2	5.8	6.0	4.9	5.5	5.9
Na. 2,4-D Ck	82.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Butyl 2,4-D (control)	29.5	2.5	3.7	6.0	3.5	6.0	6.0	3.3	5.7	6.0	3.5	5.7	6.0
Butoxyethanol 2,4-D control	33.9	1.0	1.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

[1]Evaluation of volatility is made in terms of plant response.

Reaction class	Description of formative effects[a]
1	No apparent response
2	Epinasty 1°–20°[b] compared to normal; no curling
3	Epinasty 21°–40° compared to normal + slight curling
4	Epinasty 41°–60° compared to normal + moderate curling
5	Epinasty 61°–80° compared to normal + moderately severe curling
6	Epinasty 81°—greater than 90°; severe formative effects apparent (twisting of main stem, distortion of petioles and leaflets)

[a]The plant must be regarded on the whole. Epinasty readings are made on the youngest leaves and those just preceding.

[b]Angles are measured with a protractor.

Table 2. Evaluation of response of Rutgers tomatoes at 4 intervals following exposure for 2, 4, and 16 hours at 70° to 75° F. to vapors of a variety of commercial ester formulations of 2,4–D and/or 2,4,5–T.

Formulation	Products tested	Average formative effect[1] at 4 intervals following exposure											
		Upon removal			24 hours			48 hours			72 hours		
		2	4	16	2	4	16	2	4	16	2	4	16
Butyl 2,4-D	11	2.7	4.2	5.9	5.4	5.8	6.0	5.3	5.8	6.0	5.3	5.4	6.0
Butyl 2,4,5-T	1	2.0	4.0	6.0	1.0	6.0	6.0	1.0	6.0	6.0	1.3	4.3	5.7
Butyl 2,4-D & 2,4,5-T	3	2.2	4.0	5.9	4.1	5.7	6.0	3.9	5.3	5.8	4.0	5.2	5.8
Butyl 2,4-D and Amyl 2,4,5-T	2	3.2	3.5	6.0	5.9	5.5	6.0	4.7	5.5	6.0	5.0	5.5	6.0
Isopropyl 2,4-D	9	2.1	3.7	6.0	4.9	5.8	6.0	4.6	5.6	5.9	3.9	5.3	5.8
Isopropyl 2,4,5-T	8	2.3	3.6	6.0	4.6	5.5	6.0	4.3	5.5	5.8	3.9	5.2	5.8
Isopropyl 2,4-D & 2,4,5-T	7	2.3	4.1	6.0	4.9	5.8	6.0	4.7	5.7	6.0	4.0	5.2	5.9
Isopropyl 2,4-D & 2,4,5-T; Tetrahydrofurfuryl 2,4-D & 2,4,5-T	1	1.0	2.0	5.3	1.0	3.3	6.0	1.0	2.3	6.0	1.0	2.3	6.0
Amyl 2,4,5-T	1	1.0	4.0	5.7	1.0	4.7	6.0	2.0	3.0	6.0	1.3	1.7	3.7
Pentyl 2,4-D & 2,4,5-T	2	1.8	3.2	5.3	4.1	5.8	5.7	4.0	5.4	5.2	3.5	4.8	5.2
Pentyl 2,4,5-T	3	1.4	2.6	5.4	1.7	4.6	5.6	1.9	4.3	5.6	1.9	4.0	5.4
Alkyl 2,4-D	2	2.0	3.5	6.0	5.0	5.9	6.0	4.5	5.9	6.0	3.5	5.4	5.9
Alkyl 2,4-D & 2,4,5-T	1	1.3	3.7	6.0	5.3	5.3	6.0	5.3	5.7	6.0	5.0	5.7	6.0
Tetrahydrofurfuryl 2,4-D	1	1.0	1.0	1.1	1.0	1.1	1.1	1.0	1.0	1.1	1.0	1.0	1.7
Tetrahydrofurfuryl 2,4,5-T	1	1.7	2.0	2.3	1.0	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.3
Tetrahydrofurfuryl 2,4-D & 2,4,5-T	2	1.2	1.2	1.7	1.0	1.0	1.5	1.0	1.0	1.5	1.0	1.1	1.5
Butoxyethanol 2,4,5-T	1	1.3	1.7	2.6	1.0	1.7	2.3	1.0	1.3	1.0	1.0	1.0	1.0
Butoxyethanol 2,4-D & 2,4,5-T	4	1.3	1.4	1.3	1.0	1.0	1.5	1.0	1.0	1.4	1.0	1.0	1.4
Iso-octyl 2,4-D	2	1.2	1.4	1.3	1.1	1.2	1.6	1.2	1.2	1.7	1.4	1.2	1.9
Iso-octyl 2,4,5-T	1	1.0	1.2	1.8	1.0	1.2	1.7	1.0	1.1	1.6	1.0	1.0	1.6
Propylene glycol 2,4-D & 2,4,5-T	4	1.1	1.4	1.2	1.1	1.4	1.3	1.0	1.1	1.0	1.0	1.2	1.0
Propylene glycol 2,4,5-T	3	1.1	1.0	1.0	1.0	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Butyl 2,4-D (control)	—	2.5	3.7	6.0	3.5	6.0	6.0	3.3	5.7	6.0	2.5	5.7	6.0
Butoxyethanol 2,4-D (control)	—	1.0	1.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Na. 2,4-D (Satd. aqueous soln.; check)	—	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

[1]See footnote below Table 1.

Responses of tomato plants to a variety of esters at normal temperatures:

Averages summarizing response to groups of esters formulated with the same alkyl radical are compared to other kinds of esters tested at normal temperatures and are included in Table 2. These data show that the butyl, isopropyl, amyl, pentyl, and alkyl esters (formulated from a mixture of alcohols containing 3–9 carbon atoms) are volatile whereas the butoxyethanol, tetrahydrofurfuryl, iso-octyl, and propylene glycol esters are low volatile. The consensus that 2,4,5–T esters are essentially lower in their volatility than comparable 2,4–D formulations is confirmed. Mixed volatile esters appear to have greater vapor activity than comparable 2,4,5–T formulations indicating the potentially greater hazard of the 2,4–D fraction alone or in combinations.

Responses of tomato plants to amine formulations at higher temperatures:

None of the amine formulations (See Table 3) were found to be volatile either at 90° or 120° F. since the response to vapors of each of the 18 amine formulations tested were less than 2.5. Accordingly, it appears that hazards attending the use of amines in particular

Table 3. Evaluation of response of Rutgers tomatoes at 4 intervals following exposure for 2, 4, and 16 hours to vapors of a variety of amine and other formulations of 2,4–D at 90° and 120° F.

2,4-D Formulation	Products tested	Test temp.	Average formative effect[1] at 4 intervals following exposure											
			Upon removal			24 hours			48 hours			72 hours		
			2	4	16	2	4	16	2	4	16	2	4	16
	No.	°F												
Dimethylamine	4	90	1.0	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
		120	1.3	1.3	1.7	1.1	1.2	1.2	1.0	1.0	1.1	1.1	1.3	1.3
Ethanolamine	1	90	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
		120	1.3	1.5	1.6	1.0	1.1	1.3	1.0	1.0	1.3	1.1	1.1	1.7
Diethanolamine	2	90	1.0	1.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
		120	1.2	1.6	1.2	1.0	1.2	1.0	1.2	1.0	1.2	1.8	1.7	1.9
Triethanolamine	4	90	1.0	1.2	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
		120	1.3	1.5	1.6	1.0	1.1	1.3	1.0	1.0	1.3	1.1	1.1	1.7
Isopropyl & Ethanolamine	1	90	1.0	1.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
		120	1.3	1.3	1.7	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Isopropyl & Triethanolamine	5	90	1.0	1.4	1.3	1.0	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0
		120	1.2	1.6	1.5	1.0	1.0	1.3	1.0	1.0	1.3	1.0	1.0	1.5
Alkanolamine	1	90	1.0	1.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
		120	1.0	1.5	1.4	1.0	1.0	1.0	1.0	1.0	1.2	1.8	1.3	1.8
Butyl 2,4-D ester (control)		90	3.8	4.8	5.9	5.8	5.9	6.0	5.6	5.8	6.0	4.9	5.7	5.9
		120	5.9	5.4	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Butoxyethanol ester 2,4-D: (control)		90	1.9	3.2	5.8	2.3	4.7	5.7	2.0	3.8	5.5	1.9	3.3	4.8
		120	3.3	4.8	6.0	5.5	5.8	6.0	5.6	5.9	6.0	5.3	5.9	6.0
Na. 2,4-D; sat'd aqueous soln. (check)		90	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
		120	1.3	1.3	1.3	1.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

[1]See footnote below Table 1.

areas of the West are possibly associated with climatological phenomena (high humidity and heavy fogs, for example) and topography rather than with temperature alone. It was strikingly evident that although the amines appeared to be low volatile at 90° and 120° F., ester vapor activity increased. The butyl 2,4–D ester used as a control to indicate response to a known volatile formulation increased the amount of reaction in the test plants at these higher temperatures, i.e., greater initial reaction was obtained for shorter exposures. The most severe response was now evident 24 hours after exposure and no mitigation of effects was evident even after 72 hours. The butoxyethanol 2,4–D ester (a control found to be low volatile at 70° to 75° F.) appeared to be volatile at higher temperatures. However, the saturated aqueous solution of the sodium 2,4–D salt produced no response at 90° F. and remained low volatile even at 120° F.

Responses of tomato plants to low volatile ester formulations at higher temperatures:

The volatility of individual ester formulations of 2,4–D and/or 2,4,5–T was increased as the temperature was raised from 70° to 90° and 120° F. (see Table 4.) The butoxyethanol formulation found to be low volatile at 70° F. was volatile at higher temperatures, the responses evident being more severe with rise of temperature. The propylene glycol, and tetrahydrofurfuryl products were found to be volatile only at 120° F. compared with the consistent low volatility of the sodium 2,4–D check at all temperatures.

Table 4. Evaluation of response of Rutgers tomatoes at 4 intervals following exposure for 2, 4, and 16 hours at 90° and 120° F. to vapors of ester formulations classed as low volatile at normal (70° to 75° F.) temperature.

Formulation	Test temp.	Average formative effect[1] at 4 intervals following exposure											
		Upon removal			24 hours			48 hours			72 hours		
		2	4	16	2	4	16	2	4	16	2	4	16
	°F												
Butoxyethanol 2,4-D	70	1.0	1.3	1.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	90	1.9	3.2	5.8	2.3	4.7	5.7	2.0	3.8	5.5	1.9	3.3	4.8
	120	3.3	4.8	6.0	5.5	5.8	6.0	5.6	5.9	6.0	5.3	5.9	6.0
Propylene glycol 2,4-D & 2,4,5-T	70	1.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	90	1.0	2.7	3.3	1.0	1.7	2.3	1.0	1.0	2.3	1.0	1.0	2.0
	120	2.0	3.3	5.5	3.0	4.3	5.0	2.0	2.3	5.0	1.0	2.7	5.0
Tetrahydrofurfuryl 2,4-D	70	1.0	1.0	1.1	1.0	1.1	1.1	1.0	1.0	1.1	1.0	1.0	1.7
	90	1.0	1.3	2.3	1.0	1.3	2.3	1.0	1.0	2.3	1.0	1.0	2.0
	120	2.0	3.7	5.3	5.3	6.0	6.0	3.7	5.7	6.0	2.7	5.7	5.7
Butyl 2,4-D (known volatile control)	70	2.5	3.7	6.0	3.5	6.0	6.0	3.3	5.7	6.0	2.5	5.7	6.0
	90	3.8	4.8	5.9	5.8	5.9	6.0	5.6	5.8	6.0	4.9	5.7	5.9
	120	5.9	5.4	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Na. 2,4-D; sat'd aqueous soln. (check)	70	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	90	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	120	1.3	1.3	1.3	1.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

[1]See footnote below Table 1.

Discussion and Summary

Compared with the check and controls used in all the tests made, amine formulations appeared to be low volatile at temperatures of 90° to 120° F. The lower alkyl esters (isopropyl, butyl, alkyl, amyl, and/or pentyl) have been found to be volatile at normal temperatures. The initial responses of tomato plants to the butyl ester formulation were intensified as the temperature was raised from 70° F. to 90° F. and 120° F. and the accumulated effect was not mitigated 72 hours after exposure. Some of the higher molecular weight esters although low in volatility at 70° F. caused formative responses in tomato plants at 90° F. while others (propylene glycol, and tetrahydrofurfuryl) continued to be low in volatility at 90° F., but were volatile when the temperature was raised to 120° F.

This is in agreement with the findings of others (4) who concluded from their tests that physiological activity of 2,4–D and 2,4,5–T ester herbicides increased as temperature and duration of exposure were increased.

The concept of threshold concentrations for vapors of any one group of esters containing widely different amounts of the active acids appears reasonable in accounting for the similarity of formative effects obtained despite this variation, provided all concentrations are above a "Threshold."

Products similar to the propylene glycol and tetrahydrofurfuryl formulations found to be low volatile at 90° F. might appear volatile in future tests. Past experience indicated that purity of the alcohol used for esterification might be an important factor. The amount of lower alkyl alcohols persisting as residues could, conceivably, form lower alkyl esters and thereby cause a formulation

to be volatile at 90° F. or even at normal temperature. It is also conceivable that commercial formulations may contain esters other than those designated in the labeling. Tests are now being made relative to these effects and will be reported when available.

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NOTES

Halogenated Phenyl Alkyl Ethers as Plant Growth Regulators

S. R. McLane, E. W. Dean, J. W. Brown, C. R. Connell, W. H. Howard, and C. E. Minarik

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The majority of commercial growth-regulator type herbicides are substituted phenoxy acids or their derivatives. Upon hydrolysis, these materials yield a phenoxy carboxyl type compound. The presence of a carboxyl radical initially or upon hydrolysis or rearrangement has been considered essential for activity of phenoxy herbicides (2). 4–Chloroanisole, (4–chlorophenylmethylether); 2,4–dichloroanisole, (2,4–dichlorophenylmethylether); 4–chlorophenetole, (4–chlorophenylethylether); and 2,4–dichlorophenetole, (2,4–dichlorophenylethylether) were reported in 1946 as being inactive (4). The above four compounds are essentially mixed aromatic short carbon chain alkyl ethers.

Various chlorinated phenyl long chain alkyl ethers have shown marked activity as growth regulators. The possibility that the alkyl chains are oxidized by the plant to produce a carboxyl group is not excluded when the mode of action is considered.

The response produced by these compounds is similar to 2,4–D in many respects. Broadleaf weeds have been observed to respond to 4–chlorophenyl dodecyl ether much as they do to 2,4–D. The rate

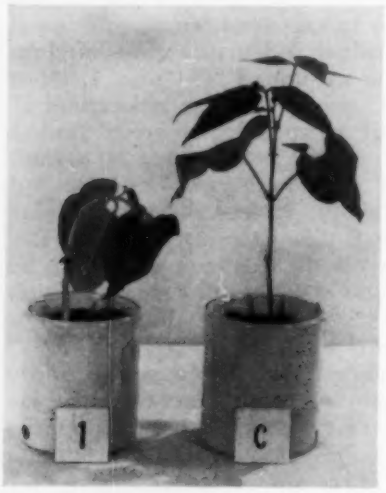


Fig. 1. A kidney bean plant treated with 2,4–dichlorophenyl hexadecyl ether (1) compared with an untreated control (C). Note the lesions produced on the stem of the treated plant.

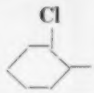
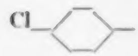
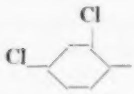
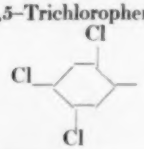
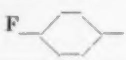
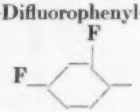
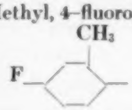
Fig. 2. Malformed foliage and fruit of beans produced by spray application of hexadecyl 4–chlorophenyl ether.

of application necessary to reduce a given weed population in an agronomic crop with this ether would be somewhat higher than a similar treatment with 2,4–D. The rapidity with which the ethers show growth response is markedly different from the phenoxy compounds. 2,4–D usually produces malformed strap shaped leaves on the new growth which expands immediately after treatment (frequently 4–5 days.) Subsequently plants treated with low doses of 2,4–D begin to show recovery. Low rates of active ethers do not produce this immediate effect when sprayed on 12 day old bean plants, but the malformation becomes increasingly severe as growth progresses. The more active compounds of the series tend to produce a more immediate effect. 4–Chlorophenyl tetradecyl ether and 2,4–dichlorophenyl hexadecyl ether when applied as a 0.25 lb/A spray have been observed to produce malformation of the first trifoliate leaf. Some ethers have been observed to produce a slight amount of initial epinasty of the primary leaf petioles of beans. Stem epinasty, as illustrated in Figure 1, occurs later. Stem tissue may proliferate with formation of galls and lesions typical of those induced by phenoxy acid compounds. Strap shaped leaves formed on tomatoes and beans are similar to those produced by application of 2,4–D or 4-chlorophenoxyacetic acid (CPA) (Figure 2 and 3). 4–Chlorophenyl hexadecyl ether was observed to produce a terminal leaf on bean plants treated with a 0.25 lb/A rate (Figure 3). Figure 2 shows a bean plant treated with the same compound which produced malformed fruit and typical 2,4–D strap shaped foliage. The 4-chlorophenyl dodecyl and hexadecyl ethers are not as effective as 2,4–D, but compare favorably with CPA.

Fig. 3. Terminal bean leaf resulting from spray application of 0.25 lb/A of hexadecyl 4–chlorophenyl ether.

The activity information in Table 1 lists the compounds injurious to twelve day old kidney bean plants. 2–Chlorophenyl hexadecyl ether was inactive, but the 4–chloro and 2,4–dichlorophenyl hexadecyl ethers were very active. The information thus far obtained indicates that, like the phenoxy acid series, high activity is limited to compounds with an even number of carbons in the aliphatic chain (3). The pattern of activity closely follows that of the phenoxy compounds with regard to the disposition of the halogen in the ring. This is illustrated by the inactivity of the ortho mono chlorophenyl substituted compounds. 2,4–dichlorophenyl tetradecyl ether appears to be considerably more active on bean plants than the 4–

***Table 1.* Activity of various halogenated phenyl alkyl ethers. ROR′**

R	OR′		Activity
2-Chlorophenyl- 	-butyl ether	$-O-(CH_2)_3CH_3$	Inactive
	-amyl ether	$-O-(CH_2)_4CH_3$	Inactive
	-octyl ether	$-O-(CH_2)_7CH_3$	Inactive
	-nonyl ether	$-O-(CH_2)_8CH_3$	Inactive
	-decyl ether	$-O-(CH_2)_9CH_3$	Inactive
	-hexadecyl ether	$-O-(CH_2)_{15}CH_3$	Inactive
4-Chlorophenyl- 	-methyl ether	$-O-CH_3$	Inactive*
	-ethyl ether	$-O-CH_2CH_3$	Inactive*
	-butyl ether	$-O-(CH_2)_3CH_3$	Inactive
	-amyl ether	$-O-(CH_2)_4CH_3$	Inactive
	-octyl ether	$-O-(CH_2)_7CH_3$	Active
	-2-octyl ether	$-O-\underset{CH_3}{\underset{\vert}{CH}}-(CH_2)_5CH_3$	Inactive
	-nonyl ether	$-O-(CH_2)_8CH_3$	Inactive
	-decyl ether	$-O-(CH_2)_9CH_3$	Active
	-undecyl ether	$-O-(CH_2)_{10}CH_3$	Inactive
	-dodecyl ether	$-O-(CH_2)_{11}CH_3$	Active
	-tetradecyl ether	$-O-(CH_2)_{13}CH_3$	Very active
	-hexadecyl ether	$-O-(CH_2)_{15}CH_3$	Active
	-octadecyl ether	$-O-(CH_2)_{17}CH_3$	Active
2,4-Dichlorophenyl- 	-methyl ether	$-O-CH_3$	Inactive*
	-ethyl ether	$-O-CH_2CH_3$	Inactive*
	-butyl ether	$-O-(CH_2)_3CH_3$	Inactive
	-amyl ether	$-O-(CH_2)_4CH_3$	Inactive
	-octyl ether	$-O-(CH_2)_7CH_3$	Active
	-nonyl ether	$-O-(CH_2)_8CH_3$	Inactive
	-decyl ether	$-O-(CH_2)_9CH_3$	Active
	-undecyl ether	$-O-(CH_2)_{10}CH_3$	Inactive
	-dodecyl ether	$-O-(CH_2)_{11}CH_3$	Active
	-tetradecyl ether	$-O-(CH_2)_{13}CH_3$	Very active
	-hexadecyl ether	$-O-(CH_2)_{15}CH_3$	Very active
2,4,5-Trichlorophenyl- 	-decyl ether	$-O-(CH_2)_9CH_3$	Sl. active
	-dodecyl ether	$-O-(CH_2)_{11}CH_3$	Sl. active
	-hexadecyl ether	$-O-(CH_2)_{15}CH_3$	Active
4-Fluorophenyl- 	-dodecyl ether	$-O-(CH_2)_{11}CH_3$	Active
2,4-Difluorophenyl- 	-dodecyl ether	$-O-(CH_2)_{11}CH_3$	Active
2-Methyl, 4-fluorophenyl- 	-dodecyl ether	$-O-(CH_2)_{11}CH_3$	Active

*From Thompson, et al.

chloro analogue. This relation is similar to that which has been observed in the phenoxy series.

The extremes to which the alkyl group of the ethers may be varied and still retain activity are being investigated. Preliminary tests indicate that in the case of the 4–chlorophenyl ethers, the 14 carbon ether is the most active with the activity decreasing as the number of carbons in the alkyl chain is increased or decreased. The 4 carbon ether of the 4–chlorophenyl series was inactive while the 8 carbon compound was active. The lower limit of activity thus appears to be between the four and eight carbon ether for the 4–chlorophenyl compounds. Preliminary tests indicate that the 14 carbon ether of the 2,4–dichlorophenyl homologous series is the most active of the entire series with the 16 carbon compound also showing very high activity.

Root elongation of several species of plants was not affected by 4–chlorophenyl dodecyl ether under conditions where 2,4–D repressed elongation. These tests were of short duration and the delayed type response produced by the ethers may be sufficiently long to have obscured their activity (1).

This new series of compounds, halogenated phenyl alkyl ethers, show marked growth-regulatory activity. The relation of the halogen position to physiological activity is quite similar to the phenoxyacetic acid series. The 4–chloro and the 2,4–dichlorophenyl tetradecyl ethers (14 carbon) are the most active of their respective series. The 2,4 dichlorophenyl tetradecyl ether is more active than the 4–chlorophenyl analogue. 2,4–dichlorophenyl tetradecyl ether and other compounds of the series (e.g., 4–chloro; 2,4,5–trichloro; 2–methyl–4–chloro; etc., as well as other alkyl groups) may offer desirable qualities as selective herbicides. Further work is proceeding at present and will be reported in the near future.

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The Occurrence and the Problem of Wild Oats in the Great Plains Region of North America

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The wild oat, *Avena fatua,* is one of the most widespread and troublesome of the numerous species of established noxious weeds. This applies to almost the entire cultivated portion of the Northern Plains of the Great Plains Region of North America. The weed is responsible for tremendous losses to farmers, chiefly through:

1. Added expense of tillage and other farm operations.
2. Reduction of yield and quality of grain.
3. Added handling, elevator, freight, and other costs.

An annual weed, introduced rather than native, wild oats came into this area well in advance of the turn of the century when pioneer settlements were becoming established. Sufficient evidence is available to indicate that wild oats were probably introduced as admixtures of seed and feed. Settlers of that day did not know the hazard the weed presented; moreover they were without adequate means of removing the seed of this weed from other seed, especially that of cereals.

For much of the data contained herein, the writer is indebted to State and Provincial Weed Supervisors who were most helpful in completing and returning a questionnaire on wild oats, describing the problem in their area.

In the Northern Plains region wild oats can be said to be a weed associated with extensive small grain farming. Where row crops and rotations that include hay and pasture crops are the rule, the weed is of little or no consequence. According to Willard (2) "Wild oats are essentially unknown in Ohio, due to regular rotating, including corn and forage crops." Sylwester (1) reports as follows: "Our rotation system, whereby small grain lands are in clover or alfalfa which are being mowed repeatedly and the land returned to corn and soybeans, keeps wild oats under control. In the last twenty years I have never actually seen wild oats in Iowa."

Wild oats rate as by far the most troublesome weed in a very large and compact block comprising the north half of South Dakota, the northwest fringe of Minnesota, much of North Dakota, Montana, and most of the three Prairie Provinces – Manitoba, Saskatchewan and Alberta. Elsewhere, within the Northern Plains, if not totally absent, their occurrence is scattered and of decidedly minor importance. By reference to the accompanying Table, it will be seen that within the infested block some 106 million acres are under cultivation. Of this total it is estimated that 61 million acres carry wild oat infestations; 29 million acres of which can be rated as very severe, and presenting a major weed control problem.

While occurring over a very wide range of soil, climatic, and other conditions, wild oats are inclined to be "choosey" as to environment. Their preference seems to be for cool, moist soil conditions. This may

Wild Oat Survey — Indicating the degree of infestation in several States and Provinces.

State or Province	Acres cropped	Acres infested	Seriously infested
Minnesota	2,679,000	1,800,000	1,311,000
South Dakota	13,347,000	5,000,000	3,000,000
North Dakota	24,000,000	12,000,000	6,000,000
Montana	12,000,000	2,500,000	1,000,000
Manitoba	9,000,000	7,500,000	3,000,000
Saskatchewan	23,560,000	18,000,000	9,000,000
Alberta	21,000,000	14,000,000	6,000,000
Br. Columbia	287,000	100,000	10,000
Totals (rounded)	106,000,000	61,000,000	29,000,000

be observed in at least two ways. First, seldom are wild oats a serious weed in the more arid and hot sections of the Northern Plains, except where moisture becomes available through irrigation. Second, wild oats are usually more abundant on the lower, damper parts of a field, especially in water runs, than they are on the knolls or southern exposures. In general, the plant seems to prefer the heavy clay soils and those of the parkland areas, rather than the drier and more arid sections.

Farmers are faced with a most difficult and complex problem in controlling wild oats. Nature has abundantly endowed the plant with characteristics to ensure its perpetuation. Most farmers find it hazardous and costly to radically change their system of farming to properly control this weed. Among the many endowed characteristics of wild oats are:

1. Early maturity and shedding of seeds before the grain crop ripens.
2. Seed dormancy and the necessity of "after ripening" before seed will germinate.
3. Low temperature requirements, which restrict the period in which seeds will germinate.
4. Viability of seed buried in the soil for long periods.

Changing from extensive mechanized grain farming, so generally the practice over the area in which wild oats are troublesome, to other systems of farming would be difficult and risky for many reasons, to mention only three:

1. Soil and climate favor extensive grain growing, rather than an intensive agriculture.
2. Mechanization and extensive farming, which are complementary to each other, are a logical development of the area, and are peculiarly adapted to it.
3. Row and fodder crops are of uncertain outcome and their profitable disposition is oftentimes a problem.

In concluding this rather general paper on the occurrence of wild oats and of the problems associated with them, the writer cannot but close on a note of optimism. Since the advent of 2,4–D, which is bringing under control many of the broad-leaved weed species, the wild oat problem has been pushed to the front, as it were. Farmers

at long last have become much more wild oat conscious. Already over much of the area there are noticeable and promising indications that a move is now under way to beat this age-old weed. With the help that is likely to be forthcoming from weed scientists, ultimate success in controlling wild oats would seem possible and likely.

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2. WILLARD, C. J. Unpublished questionnaire to author.

Wild Oats — Progress in Cultural Control

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Introduction

This weed is a companion crop particularly with spring seeded cereals and flax. Because of this there is the possibility that as long as grain constitutes the only crop in a rotation, wild oats will present a constant, if not ever-increasing weed problem. Since grain farming is likely to be the preferred system over the Central Plains region of Canada and northern U.S.A. for a long time to come, the challenge is to discover methods of subduing wild oats on land that is continually devoted to small grain crops. In a questionnaire sent to 580 farmers in western Manitoba by the Brandon Farm in 1953, 95 per cent of replies listed wild oats as the weed of first importance.

Relationship of Seed Dormancy to Cultural Control

Success in the application of cultural practices for the control of wild oats depends very largely on a knowledge of the botanical characteristics of the plant. Lindsay (5) states that an examination in 1952 of some 450 wild oat specimens from five selected areas in prairie Canada showed that most of the plants could be placed into the *Avena fatua* ssp. *fatua* group and that these specimens could be grouped into four varieties of ssp. *fatua* viz. *pilossissima glabrata, intermedia* and *vilis*. Taxonomic studies revealed that *pilossissima* and *intermedia* were rather uniform morphologically but that *glabrata* and *vilis* were more variable. All varieties in tests so far conducted appear to possess similar "dormancy" characteristics.

Wood (6) lists the following as the more important among the characteristics of wild oats that render it a difficult weed to control.

1. Early maturity and shedding of seeds before the cultivated grain crop ripens.
2. Seed dormancy and the necessity of "after ripening" before seed will germinate.
3. Low temperature requirements which restrict the period in which seeds will germinate.
4. Retention of viability of seed buried in the soil for long periods.

Of the numerous characteristics that render control of wild oats a perplexing problem, seed dormancy is of first importance and for this reason research associated with this weed has been mainly for the purpose of discovering the reasons lying behind the habitual uncertainty of wild oats seeds to germinate.

Johnson (4) in an extensive study concluded that delayed germination in A. *fatua* is due to agencies operating after, and influenced by fertilization, which effect the development or absorption of tissues enveloping the embryo in such a manner as to prevent germination of the seed until after a certain period of after ripening has

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elapsed. Experiments conducted by Johnson proved that dormancy was broken by drying newly matured seed constantly at 21°C for 90 days, but that secondary dormancy could be induced by a ten-day break in the continuity of dry, even temperature in the storage chamber.

The findings of Johnson have been supported by germination tests of A. *fatua* conducted at the Brandon Farm. In 1951 mature seed was collected from panicles in the field Aug. 20. Comparisons were made of un-interrupted dry storage at 75°F. and storage in damp soil at outdoor temperatures. Germination tests began in the greenhouse Oct. 20. Fresh lots of seed were taken from the respective storages and planted at monthly intervals up to April 1952. In the October test seed held at room temperature under dry conditions germinated 63 per cent; that stored outdoors in damp soil 12 per cent. November and December plantings showed respective declines to 46 and 6 per cent, but, from the April plantings seed held throughout the winter in dry storage at 75°F. germinated 88 per cent compared with 6 per cent for seed held outdoors in damp frozen soil. In 1953 seed collected from mature panicles in the field Aug. 12 and held constantly in dry room temperature at 75°F. until Oct. 1, on which date it was planted in the greenhouse, germinated 75 per cent at a soil temperature of 68°F. Seed from the same field threshed Sept. 7 and held in bin storage till Oct. 1, germinated 9 per cent. Year-old seed from granary bin storage germinated 12 per cent and 1953 seed dropped to the ground during August, picked from the surface and planted Oct. 1, germinated 3 per cent. Seed from burned over stubble by comparison germinated 9 per cent.

It is undoubtedly due to these peculiar, and oft times uncertain, seed dormancy habits that many, and, sometimes contradictory methods of cultural control have been developed by farmers and experimental stations.

RESULTS OF TILLAGE AND CROPPING EXPERIMENTS

In order to clarify and possibly add to what is already known about cultural control a new project was started on five Experiment Stations in Western Canada in 1951. This project is confined to tillage methods that can be employed by the farmer who engages exclusively in grain growing. Methods include the use of an early maturing spring seeded crop such as barley. Seeding is done at the normal time compared with a delayed date. Tillage methods associated with each date of seeding include fall versus no fall tillage of stubble, and, post-seeding versus no post-seeding tillage. On all plots standard pre-seeding cultivation is employed as necessary to kill all weeds.

(1) *Delayed Seeding.* In 1952 at Brandon plots seeded to barley May 8, averaged 28.5 wild oat plants per square yard, compared with 4.4 plants in plots seeded June 11. Counts were made at heading and one week prior to harvest. Barley yielded 52 bushels per acre on plots seeded at normal time (May 8) and 50.5 on plots seeded June 11. Delayed seeding generally contributes to lower yields

and quality of grain (1). Since however, late seeding provides time and opportunity to "grow out" and kill wild oats before drilling the crop, the benefits of weed control must be weighed against the probability of harvesting a poorer crop.

(2) *Fall Tillage.* This method compared with no fall tillage of stubble gave no appreciable reduction in the stand of wild oats in the 1952 crop. In an experiment conducted from 1937 to 1953 fall tillage of stubble in preparation for crop the following year has, however, reduced the incidence of wild oats by 30 per cent (3). Experiments at Brandon prove that less than 10 per cent of the new crop seed of wild oats grows under field conditions during the intervening days between harvest and freeze-up. Fall tillage may encourage old seed lying in the soil to germinate. The time of tillage of stubble in the autumn is not as important, however, as doing a job that will prepare a good seed bed and properly cover the weed seeds with soil so that they will find their environment conducive to growth the next spring. In an experiment at Brandon extending from 1948 to 1952 (2), stubble land turned over in the autumn to a depth of 2.5 inches with the mould-board plough produced 42 per cent less wild oat seed in the threshed grain of the following crop than stubble worked with the one-way disc. Discing in contrast to ploughing left much of the wild oat seed uncovered, especially after snow melted in the spring, consequently the growth of wild oats that could be destroyed by pre-seeding tillage was much better on the shallow ploughing.

(3) *Pre-seeding Tillage.* This is of utmost importance. Stubble that has not been tilled the previous autumn should be worked early in the spring to bury the wild oat seed. Harrowing and packing should follow. If wild oats are to be killed by tillage immediately before seeding, the plants should at least be in the two-leaf stage when the work is done.

(4) *Post-Seeding Tillage.* Under favourable conditions tilling the surface with a rod or wire weeder just as the cotyledon of the cultivated grain is nearing the surface is an effective method of controlling wild oats. Once or twice over with drag harrows at the same stage may also be advantageously used. On barley plots at Brandon in 1952 post-seeding tillage with a rod weeder reduced the stand of wild oats from 15.7 plants per square yard to 10.2.

(5) *Summerfallow.* When carefully managed, a year of fallow will "grow out" a large percentage of the wild oats seed lying to a depth of five inches. On fields heavily impregnated with seed that has accumulated through successive years of wild oats infested crop, all that can be expected from the best managed fallow is a substantial reduction in the viable seed incorporated in the soil. Summerfallow fields, in a grain rotation that has been underway since 1911 on the Brandon Farm, and on which three good kills of successive crops of wild oats were made between May and October 1953, still retained 20 bushels of viable seed per acre to a depth of four inches at time of sampling and analysis October 20. The efficiency of the summerfallow for the control of wild oats is augmented if the soil

is left undisturbed for a lengthy period after each successive growth is killed.

CROPPING SYSTEMS

Seeding to Grass and Legumes. Grassing down land while conceded to be a good method of controlling wild oats has not brought the expected relief in many instances. This is because the heavy accumulation of wild oats seed in the surface soil of the average grain field assures that much of this lies dormant for several years and an initial retirement to grass for two or even five years cannot be expected to eradicate the weed.

There is proof at the Brandon Farm that grassing down as a regular practice in a crop rotation will eventually bring relief from wild oats. Two crop rotations were started thirty years ago on an area evenly and moderately infested with wild oats. One is a four-year rotation of fallow, wheat, wheat, oats; the other is essentially this same four-year rotation extended to six years by including a legume-grass mixture for hay between the two wheat crops. During the five years 1948–52 inclusive, threshed grain on the four-year rotation had an average wild oats content by weight of 1.8 per cent in wheat on fallow, 6.5 per cent in wheat after wheat and 10.3 per cent in third crop oats. By comparison, for the past ten years the wild oats content in threshed grain from all fields in the six-year rotation has seldom reached measurable proportions. In this rotation the weed no longer presents a tillage problem, whereas on the grain rotation frequent tillage, delayed seeding, and, other practices are annually employed in order to hold the weed in check.

FALL SEEDED WINTER CROPS

Grain crops seeded on fallow or on a clean stubble preparation late in August or early September compete successfully with wild oats. Winter rye used by the Brandon Farm on the Reclamation Station at Melita, Manitoba, between the years 1935 and 1953 has been found useful not only for preventing the spread of wild oats to clean land, but for the gradual reduction of the weed when used in a rotation on wild oats infested fields (3). Winter wheat has similar advantages wherever it can be grown.

SUMMARY AND CONCLUSIONS

Dormancy characteristics of the wild oats seed are reasons why this plant has precipitated an economic weed problem of major proportions among grain farmers in the north central plains section of the U.S.A. and in the three prairie provinces of Canada.

Experimental evidence supports the conclusion that a lengthy but variable period of after-ripening is necessary before the seed will germinate. The breaking of dormancy is hastened by subjecting the seed to constantly dry warm conditions. On the other hand seed stored in damp cool soil from the time it drops from the panicle, holds dormancy at least through the autumn months, and, frequently much of this seed lies in a viable state in the soil for a number of years.

Control of wild oats in a straight grain system of farming is difficult. At the Experimental Farm, Brandon, Man., methods affording the best measure of control have been delayed seedings of an early maturing crop such as barley; post-seeding cultivation; the careful management of summerfallow and the inclusion of winter rye in the rotation.

Grassing down for two or more years as a regular feature in a rotation of crops has proved to be the best permanent measure for the cultural control of wild oats on the Brandon Experimental Farm.

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Comments: On Distribution of CIPC in Soil

BLAINE O. PRAY[1] and EUGENE D. WITMAN[2]

IT IS well recognized that the effectiveness of a herbicide is dependent on its relative activity and its life in the soil. With increasing use of various organic herbicides it has become important to have knowledge of each of these factors.

One of these new organic chemicals, isopropyl N–3–chlorophenylcarbamate (CIPC) has been the subject of a recent investigation (4) in which a chemical method suitable for the determination of small amounts of CIPC was developed. It would be of considerable interest to determine, by such a method, the amount of CIPC residue remaining in the soil a period of time after the actual application of this chemical as a pre-emergence herbicide. At the same time, the probable location of this residue with respect to soil depth would help to establish whether or not migration in the soil was a factor to be considered in the re-planting of treated areas. Freed (3) demonstrated that water is essential to the action of isopropyl N–phenylcarbamate (IPC) and that moisture and high soil temperature hasten the destruction of IPC. Laboratory experiments with glass columns containing soil were used by Freed (3) to show that IPC supplied to the soil was distributed down to a depth of about ten inches.

Mitchell (2) has published information which demonstrates that much CIPC must be lost by volatilization. Bacterial attack (1) may also account for a portion of the material applied. Recently Smith and Ennis (5) have shown that movement of CIPC in soil varies with the formulation and that most of the CIPC is concentrated in the top inch. The distribution of CIPC in soil as measured by a chemical method would add to the information now available on the fate of herbicides in the soil.

To measure the distribution of CIPC in sandy loam soil, samples were taken from a cotton field at the Edisto Experiment Station.[3] The field was sprayed with a 48% emulsifiable formulation of CIPC in water at the rate of 7.5 lbs. of active ingredient per acre. Two series of random samples were taken nineteen days after application from two test plots, A and B, used for the pre-emergence treatment of cotton. Rains of 0.91, 0.65 and 0.12 inch fell 4, 6 and 7 days, respectively, after treatment. The maximal temperature ranged from 65 to 96° F.; the minimal temperature ranged from 49 to 60° F.

The soil samples were shipped to Barberton, Ohio where they were kept under refrigeration at –20° F. until analyzed. This precaution was taken to avoid any additional loss of CIPC by volatilization or decomposition. Eight 200-gram samples were taken at 0.5-

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Table 1. Analysis of soil samples taken from test plots receiving pre-emergence treatment with CIPC at Blackville, S. C.

Plot		CIPC found			
		A		B	
Sample	Depth, inches	p.p.m.	%	p.p.m.	%
1	0–0.5	0.71	57.8	2.84	63.1
2	0.5–1.0	0.43	35.0	1.37	30.3
3	1.0–1.5	0.04	3.4	0.27	6.0
4	1.5–2.0	0.05	3.9	0.02	0.5
5	2.0–2.5	0.00	—	0.01	—
6	2.5–3.0	0.00	—	0.00	—
7	3.0–3.5	—	—	0.00	—
8	3.5–4.0	0.00	—	—	—

inch intervals of depth from each plot. These samples were analyzed by the method of Gard and Rudd (4) to obtain the data listed in Table 1.

Examination of the data in Table 1 indicates that all of the CIPC exists in the top 2 inches of soil. Taking the weight of an acre of soil two inches in depth as 600,000 lbs., the calculated CIPC (7.5 lbs. per acre) in this amount of soil was initially 12.5 p.p.m.

Thus, the data indicates that 10% and 36% of the initial CIPC applied to plots A and B, respectively, remained in the soil at the time of analysis. The remaining material was found to be distributed largely in the top half-inch of soil and significantly in the second half-inch.

CONCLUSIONS

1. CIPC applied to cotton test plots as a pre-emergence herbicide is largely lost from the soil after a period of three weeks under these conditions.

2. Residual CIPC at the end of this period is concentrated in the top one inch of soil.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the invaluable help of Nolan Rudd, Columbia-Southern Research Laboratory and Messrs. Balk and Powers, Edisto Experiment Station.

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New Herbicide Controlled Oak Brush and Resulted in Increased Native Grass Production

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THE new, low volatile polypropylene glycol butyl ether ester of 2,4,5–trichlorophenoxypropionic acid (2,4,5–TP)† was used as a foliage spray on dense stands of brush and trees. Hardwood species of the post oak and blackjack oak type were treated. Applications of the low volatile ester of 2,4,5–TP were made with both airplane and ground sprayers in 1951, 1952, and 1953 at the Red Plains Conservation Experiment Station, Guthrie, Oklahoma, and at four other locations in the state. They were applied in the spring when the plants reached full leaf size, and later in the summer when they were in a semi-dormant condition because of dry weather.

Aerial treatments varied from 0.8 to 2 pounds acid equivalent per acre. Each rate of the chemical was applied in an emulsion of 4 gallons of water and 1 gallon of diesel oil. Applications with ground equipment involved a comparison of the polypropylene glycol butyl ether ester of 2,4,5–TP at 3 pounds acid equivalent per acre with a mixture of 1.5 pounds acid equivalent per acre of the propylene glycol butyl ether ester of 2,4–D and 1.5 pounds acid equivalent per acre of the polypropylene glycol butyl ether ester of 2,4,5–TP. These two treatments were compared to adjacent treatments of the propylene glycol butyl ether ester of 2,4,5–trichlorophenoxyacetic acid (2,4,5–T) at similar rates of application. All treatments were applied as a wetting spray using 100 gallons of water per acre.

The action of the new chemical was not noticeable for 10 to 12 days. After this time, a gradual browning of the leaves developed and many of them remained on the plants until forced to drop by ice or sleet several months later. The new herbicide was superior to the propylene glycol butyl ether ester of 2,4,5–T in the airplane tests. The single treatment was more effective on post oak than on blackjack oak. On 5 acres aerially sprayed twice in successive years, 73 per cent of all the oaks were defoliated the second year with no resprouting and there has been no resprouting since the initial treatments were made. About the same percentage of defoliation occurred on red bud, elm, and chittam trees. Nearly a 100 per cent kill was obtained on sumac, but there was no effect on chickasaw plums. There was a 90 to 95 per cent defoliation of all the oaks at the end of the second year as a result of two annual sprayings with ground

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The experimental chemicals used in this study were supplied by the Dow Chemical Company. The author wishes to acknowledge the cooperation of L. L. Coulter and J. W. Gibson of the Dow Chemical Company for their assistance and suggestions during these investigations.

†The Dow Chemical Company has proposed "silvex" as the common name for 2,4,5–trichlorophenoxy propionic acid.

machines. The mixture* of 2,4,5–TP with 2,4–D applied under similar conditions, produced about the same degree of defoliation. Applications made during the semi-dormant summer period produced very poor results.

Annual production of native grass hay was increased 14 times or from 156 pounds per acre on the untreated brush to 2,185 pounds per acre on the aerial treated plots, receiving the two annual applications of 2 pounds per acre. Control of broadleaved weeds on this area was very good.

BOOK REVIEW

Relationship Between Chemical Structure and Toxic Action on Rats, by James B. DeWitt, Ervin Bellack, Clarence W. Klingensmith, Justus C. Ward and Ray Treichler; and Relationship Between Chemical Structure and Rat Repellency, by Ervin Bellack, James B. DeWitt and Ray Treichler. Chemical-Biological Coordination Center Review No. 5. National Research Council, Washington, D. C. 156 pages. 1953. $1.75 postpaid.

The two technical reports which are published in this review present results obtained by the United States Department of Interior Fish and Wildlife Service in the screening of a large number of compounds for toxic action and repellency to rats. In the first study, data on the toxicity to rodents of approximately 1,000 chemical compounds and plant extracts were obtained. In addition to a test on the toxicity of each compound, each series of compounds was also evaluated on ability to meet the additional prime requirements of acceptability sufficient to insure that the rodents would readily ingest lethal quantities, stability, and possible specificity, in that the toxicant would be lethal to rodents and relatively innocuous to other species. The compounds tested and their minimum lethal dosages are presented in tabular form.

The second report also presents the results in brief discussion and in tabular form, with a repellency index of each compound, of tests conducted on 2700 materials. As pointed out by the authors, a repellent material should be non-hazardous in end-use form, stable under varied storage conditions for a considerable period of time, and capable of ready application during fabrication. The tests were made in a search for a compound which might be used for protection of materials in temporary storage dumps, and the results presented are those obtained by means of a food-acceptance technique.

W. C. ROBOCKER

*Polypropylene and propylene glycol butyl ether esters of 2,4,5–TP and 2,4–D.

News and WEED Affairs

The seventh Southern Weed Conference will be held in Hotel Peabody, Memphis, Tennessee on the afternoon of January 11 and all day January 12 and 13. The officers for this meeting are as follows:

Dr. W. B. Ennis, Jr. ..... President
State College, Mississippi

Dr. W. C. Shaw ..... Vice-President
Division of Weed Investigations
Bureau of Plant Industry
Beltsville, Maryland

Dr. G. C. Klingman ..... Secretary-Treasurer
State College, North Carolina

Dr. P. J. Talley ..... Program Chairman
Lion Oil Company, Eldorado, Arkansas

A chemical and equipment display is planned. Those interested in chemical and equipment display facilities should contact Mr. O. B. Wooten, Chairman of the Chemical and Equipment Display Committee, Delta Branch Experiment Station, Stoneville, Mississippi.

Chipman Chemical Company Releases New Weed Control Booklet

An up-to-date revision of "You Can't Argue with Weeds" has just been issued by Chipman Chemical Company, manufacturers of chemical weed killers since 1912. This 40 page booklet contains helpful information on a wide variety of chemicals currently recommended for weed, grass and brush control – explaining what they are, what they are used for and how to use them. In addition, many pages are devoted to illustrations and detailed descriptions of the most troublesome weeds, as well as specific directions for their control. Considerable information on killing brush, trees and stumps is also included.

A copy of "You Can't Argue with Weeds" may be obtained without obligation by writing to Chipman Chemical Company, Inc., Dept. 22, Bound Brook, N. J.

BIBLIOGRAPHY OF WEED INVESTIGATIONS
for April, May, and June, 1953

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Prepared By

Division of Weed Investigations, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, United States Department of Agriculture

This bibliography of current literature on weeds and their control is issued as a service to those engaged in weed research in the United States and other countries. In issuing this bibliography the Division of Weed Investigations does not assume responsibility for the subject matter cited.

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